UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
INSTITUTO DE INFORMÁTICA
PROGRAMA DE PÓS-GRADUAÇÃO EM COMPUTAÇÃO

RAFAEL VALER

Musical Brush: Development and Exploration of a Tool that Supports Creativity by Combining Music with Drawing

Thesis presented in partial fulfillment
of the requirements for the degree of
Master of Computer Science

Advisor: Prof. Dr. Luciana Porcher Nedel
Coadvisor: Prof. Dr. Rodrigo Schramm

Porto Alegre
November 2020

CIP — CATALOGING-IN-PUBLICATION

Valer, Rafael

Musical Brush: Development and Exploration of a Tool that Supports Creativity by Combining Music with Drawing / Rafael Valer. – Porto Alegre: PPGC da UFRGS, 2020.

107 f.: il.

Thesis (Master) – Universidade Federal do Rio Grande do Sul. Programa de Pós-Graduação em Computação, Porto Alegre, BR–RS, 2020. Advisor: Luciana Porcher Nedel; Coadvisor: Rodrigo Schramm.

1. Music. 2. Drawing. 3. Creativity. 4. Augmented reality. 5. Creativity support tools. I. Porcher Nedel, Luciana. II. Schramm, Rodrigo. III. Título.

“Life can be much broader once you discover one simple fact:
Everything around you that you call life was made up
by people that were no smarter than you.”

— Steve Jobs

ACKNOWLEDGEMENTS

First, I thank my family for their unconditional support during my studies, without which I could not develop this research and complete this Master's course.

Secondly, I thank my advisor, Prof. Luciana Nedel, and co-advisor, Prof. Rodrigo Schramm, for their dedicated support and guidance throughout this project.

Importantly, I thank the Federal University of Rio Grande do Sul, its Institute of Informatics and Graduate Program in Computer Science for its continued efforts in promoting international-level research.

I acknowledge the funding from the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), which was crucial for the realiztion of this project.

Finally, I would like to thank all the participants who kindly volunteered to contribute to the different phases of this work.. . .

CONTENTS

LIST OF ABBREVIATIONS AND ACRONYMS **7**
LIST OF FIGURES **8**
LIST OF TABLES **11**
ABSTRACT **12**
RESUMO **13**
1 INTRODUCTION **15**
1.1 Motivation **15**
1.2 Research Questions and Approach **16**
1.3 Objective and Contributions **18**
1.4 Structure of this Dissertation **18**
2 RELATED WORK **20**
2.1 Gestural Interaction for Musical Expression **20**
2.2 Drawing-based Musical Tools **22**
2.3 Music and Immersion **26**
2.4 Creativity Support Tools **29**
2.5 Summary **31**
3 MUSICAL BRUSH - SYSTEM DESIGN **32**
3.1 System Overview **32**
3.1.1 Execution Modes 33
3.1.2 Design Rationale 34
3.2 Mapping Strategies **36**
3.2.1 Sound Mapping 37
3.2.2 Visual Mapping 39
3.3 Technical Details and Choices **40**
3.4 Feature Extraction **42**
3.5 Summary **43**
4 USER STUDY I - INTERFACE EVALUATION **44**
4.1 Experiment Design **44**
4.1.1 Tasks 44
4.1.2 Questionnaires 45
4.1.3 Subjects 46
4.1.4 Protocol 46
4.2 Results **47**
4.2.1 Objective Evaluation 47
4.2.2 Subjective Evaluation 48
4.3 Discussion **54**
4.4 Prototype Modifications **55**
4.5 Summary **56**
5 USER STUDY II - CREATIVITY SUPPORT EVALUATION **58**
5.1 Creativity Evaluation **58**
5.2 Experiment Design **60**
5.2.1 Compared Versions 60
5.2.2 Hypotheses 61
5.2.3 Protocol 63
5.2.4 Questionnaires 64
5.2.5 Usage Logs 65
5.2.6 Population 66

5.3 Results **66**
5.3.1 Resulting Data 68
5.4 Discussion **71**
5.4.1 Sound vs. Visual Feedback 72
5.4.2 Two-dimensional vs. Three-dimensional 74
5.4.3 Augmented Reality 75
5.5 Summary **76**
6 CONCLUSIONS **77**
6.1 Contributions **77**
6.2 Future Works **78**
6.3 Achievements and Publications **79**
REFERENCES **81**
APPENDIX A — USER STUDY I: PRE-QUESTIONNAIRE **91**
APPENDIX B — USER STUDY I: TASKS QUESTIONNAIRE **92**
APPENDIX C — USER STUDY I: OVERALL QUESTIONNAIRE **95**
APPENDIX D — USER STUDY II: PRE-QUESTIONNAIRE **97**
APPENDIX E — USER STUDY II: CSI QUESTIONNAIRE **99**
APPENDIX F — USER STUDY II: CSI POS-QUESTIONNAIRE **101**
APPENDIX G — USER STUDY II: POS-QUESTIONNAIRE **103**

LIST OF ABBREVIATIONS AND ACRONYMS

2D	Two dimensions
3D	Three dimensions
API	Application Programming Interface
AR	Augmented Reality
CAVE	Cave Automatic Virtual Environment
CST	Creativity Support Tools
CSI	Creativity Support Index
C&C	Creativity & Cognition
DAC	Digital Audio Converter
DMI	Digital Musical Instrument
HCI	Human-Computer Interaction
HMD	Head-Mounted Display
MR	Mixed Reality
NIME	New Interfaces for Musical Expression
PD	Pure Data
SO	Sound Only
VR	Virtual Reality

LIST OF FIGURES

Figure 2.1 In *3DinMotion*, the skeleton of a subject is captured in real time and displayed as an avatar, as well as sonified based on a series of mapping rules. The motion capture dimensions include body posture, space, and time..................21
Figure 2.2 Example of performances created using the *Vuzik* (left) and the *Hyperscore* (right) systems. Both applications enable users to create music through two dimensional (2D) drawings. Visual aspects like stroke shapes and colors represent different sound characteristics such as distinct timbres or general effects.23
Figure 2.3 Similar to a social network for music, *Microjam* encourages users to improvise and share performances. Touch gestures on a SmartScreen are used to create the 2D drawings and generate sounds. The pitch is impacted by the horizontal and vertical position of the strokes on the screen, while the timbre is represented by the stroke color...25
Figure 2.4 Left: *PaperTonnetz* main interface representing three Tonnetze and one sequencer. Right: Visualization of drawn paths in the Tonnetz...............................25
Figure 2.5 Screenshot of the Griddy prototype. The drawn lines are interpreted and transformed into music in different forms. Characteristics such as the drawing curvature speed determine, for instance, the amplitude and the note to be executed. The grid represents different chords, and when drawing inside its region manipulates the note to be played. 26
Figure 2.6 The Reactable is an electronic musical instrument that explores a tabletop tangible user interface. Users can physically manipulate these physical objects to control sounds and visual outputs..27
Figure 2.7 Bloom Open Space is an AR collaborative application that represents sounds through floating bubbles in the 3D environment. Through the use of HMD users are able to visualize and create the virtual bubbles. 28

Figure 3.1 Component used to switch among the different execution modes of the application. From the left to right, the buttons' purposes are respectively: stop execution, pause execution and start recording a new track. The slider bar represents the current timestep of the performance and advances with along with the time while playing..33
Figure 3.2 Examples of multitrack performances created using Musical Brush. The colored virtual strokes represent the melody of the piece.......................................35
Figure 3.3 Example of the different visual mapping characteristics present in *Musical Brush*. The Figures (a), (b), and (c) bring, respectively, representations of different trace colors, thickness, and animations. 41
Figure 3.4 Sound and visual mapping flows. The device sensors are responsible for extracting the values of the features such as acceleration and 3D position in the environement. Then, the corresponding values are forwarded to both the Pure Data and Metal modules, where they will, respectively, be responsible for generating the sound and graphics content. 42

Figure 4.1 *Task 1:* subjects were asked whether the two samples were equal or not. *Task 2:* after listening for a sample sound, users were asked to try to reproduce it using Musical Brush. *Task 3:* participants were requested to replicate a sample performance. *Task 4:* creational task, users were requested to create a free performance. 45

Figure 4.2 Results from T2, showing the number of participants able to reproduce the pitch, timbre, and amplitude for each of the tested samples. Pitch (blue) and timbre (green) were the sound characteristics with the highest correct reproduction rate, while amplitude (yellow) presented a very low reproducibility. The five first graphs (from left to right) bring the result individually for each tested Sample, while the last brings the average results. 48
Figure 4.3 The graph brings the users' perspective regarding the difficulty level of reproducing and additively comparing the samples concerning individual sound characteristics (amplitude, pitch, and timbre). we used a 5-points Likert scale where 1 means "Very Easy" and 5 means "Very Difficult". 49
Figure 4.4 The figure presents the impact that both drawing and sound outputs had on participants during tasks T3 and T4 on a 5-points Likert scale where 1 means "Strongly Disagree" and 5 means "Strongly Agree". The results show that while performing task T3, the subjects were slightly more impacted by the visual strokes than by the sound. 49
Figure 4.5 The figure brings Q5 results regarding the overall experience of the app usage on a 5-points Likert scale where 1 means "Strongly Disagree" and 5 means "Strongly Agree". 50

Figure 5.1 The figure details the equation for scoring the CSI. The score is obtained by summing the agreement rating statements for each factor. After that, each factor subtotal is multiplied by its factor comparison count (i.e., the number of times the factor was chosen during the paired-factor comparison. Lastly, the sum is divided by three, resulting in a value ranging from 0 to 100........................59
Figure 5.2 Screenshots from each of the four distinct compared versions of Musical Brush. Subfigures 5.2a, 5.2b, 5.2c, and 5.2d bring respectively examples of performances in the 2D, 3D, SO, and AR versions. 62
Figure 5.3 The image shows one of the study participants performing tasks while using the AR version..65
Figure 5.4 The graphs present demographic information from participants. Figure (a) brings information regarding previous experience in music practice. Figure (b) and (c) detail, respectively, the participants' experience with applications that explore music creation and Augmented Reality. 67
Figure 5.5 Histogram presenting the results for the Divergent Thinking Test. The horizontal axis represents the test score ranges, while the vertical axis represents the number of participants with the score within that range...........................67
Figure 5.6 Results from Q2 for each attribute measured by the CSI and its final score. The results were provided through user feedback and represent the average of two distinct questions, with a score ranging from 1 to 10 concerning the creativity support for each of the analyzed attributes. Significant differences were observed regarding *Results Worth Effort*, *Exploration*, *Expressiveness*, and the *CSI Score* between AR and SO conditions. 69
Figure 5.7 Graph brings the results of Q3, where users had to inform in a pairwise comparison among all the 5 creativity-related attributes, which he/she prioritized during the experiments. Results show that Exploration (28%) and Expressiveness (23%) were the most essential creative-related characteristics for users during the composition task. 70
Figure 5.8 Correlation matrix presenting the correlation coefficients when comparing the different measured variables. The color of each cell represents the value of the correlation, ranging from red (positive correlation) to blue (negative correlation). 71

Figure 5.9 The figure presents the perceived influence that both drawing and sound outputs had over participants while creating performances with *Musical Brush*. It is used a 5-points Likert scale where 1 means “Strongly Disagree” and 5 means “Strongly Agree”. 73

LIST OF TABLES

Table 4.1 Participants comments and observations regarding *Musical Brush* main features and characteristics during the user study. 54
Table 4.2 A summary of the modifications applied to *Musical Brush* after collecting feedback in our first exploratory user study. 56

Table 5.1 A summary of the characteristics of each application version. Real Env. (Real Environment), Virtual Env. (Virtual Environment) and Black Img. (Black Image) 61
Table 5.2 Final CSI Score and individual creativity attribute scores for each of the four compared versions. Bold values indicate the highest average value. 68
Table 5.3 Summary of usage logs for each of the four compared versions. Bold values indicate the highest average value, while '-' denotes that the variable was not measured for such condition. The *AR* version presented the highest average for duration time and number of created/discarded tracks. The *3D*, on the other hand, was the one with the highest levels of device displacement while performing. No significant differences were found for the different modes. 70

ABSTRACT

The use of digital tools has become a standard in several activities of our daily lives. In the music domain, the exploration of digital music has continuously increased since the rise of electronic music and sound synthesis back in the 60s, for example culminating in a wide range of musical instruments available nowadays. Along with new devices, the advancements in technology contributed to the emergence of alternative ways to interact and express music. Examples range from musical applications exploring Augmented, Mixed, and Virtual realities for sound visualization to mobile applications that make use of several sensors to control musical parameters.

In this work, we introduce *Musical Brush*, a novel artistic application that combines music and drawing. The application's main purpose is to provide an easy way for novice users to compose and express musically. *Musical Brush* is designed for mobile devices and explores Augmented Reality to create a visual representation of music in real-time. The application provides a very expressive experience in a portable setup through the use of the embedded sensors present in a smartphone.

In a first exploratory study, we collect overview feedback regarding the usage, interface, and interactions. From the results, we designed and developed improvements on some of the application audiovisual mapping gestures, which were not perceived as intuitive as expected. A positive finding was the high level of user engagement and enjoyability while handling the application, mainly caused by the tool's ability to draw in three dimensions. Taking into consideration the strong relation between *Musical Brush* and 'Creativity' during the improvisation process, allied with the growing interest of the Human-Computer Interaction community toward this topic, particularly in the study of Creativity Support Tools, we proposed a second investigation focused on exploring the capability of *Musical Brush* to support the creativity of individuals. The user study was carried out comparing four different versions of Musical Brush, analyzing distinct degrees of interaction and audiovisual feedback. We demonstrate that our application presents good results regarding the ability to support creativity-related attributes such as *'Results Worth Effort'*, *'Exploration'*, and *'Expressiveness'*. Among the reasons, the visual feedback through virtual three-dimension drawings was the key application feature responsible for this contribution.

Keywords: Music. drawing. creativity. augmented reality. creativity support tools.

Musical Brush: Desenvolvimento e Exploração de uma Ferramenta que apoia a Criatividade combinando Música com Desenho

RESUMO

O uso de ferramentas digitais tornou-se comum em várias das nossas atividades diárias. Na música, a exploração da música digital tem aumentado continuamente desde o surgimento da música eletrônica e da síntese sonora nos anos 60, culminando, por exemplo, em uma ampla gama de instrumentos musicais disponíveis nos dias de hoje. Juntamente com novos dispositivos, os avanços na tecnologia em geral contribuíram para o surgimento de novas formas alternativas de interação e expressão musical. Exemplos incluem aplicativos musicais que exploram Realidade Aumentada, Mista e Virtual para visualização sonora em aplicativos móveis e que fazem uso de vários sensores para controlar parâmetros musicais.

Neste trabalho, apresentamos o *Musical Brush*, um novo aplicativo artístico que combina música e desenho. O principal objetivo da aplicação é prover uma maneira fácil para usuários iniciantes comporem e se expressarem musicalmente. *Musical Brush* é projetado para dispositivos móveis e explora a Realidade Aumentada para criar uma representação visual da música em tempo real, fornecendo assim uma experiência extremamente expressiva e em uma configuração portátil através do uso de sensores incorporados em um smartphone. Em um primeiro estudo exploratório, coletamos opiniões gerais sobre *Musical Brush* em relação ao seu uso, sua interface e suas interações. A partir dos resultados, projetamos e desenvolvemos melhorias em algumas das interações que tem como objetivo controlar parâmetros musicais, as quais mostraram não ser tão intuitivas quanto esperado. Uma descoberta positiva foi o alto nível de envolvimento e satisfação dos participantes ao usarem a aplicação, causado principalmente pela capacidade de criar desenhos em três dimensões.

Levando em consideração a forte relação entre *Musical Brush* e a 'Criatividade' durante o processo de composição, aliada ao crescente interesse por parte da comunidade de Interação Humano-Computador neste tópico, mais particularmente no estudo de Ferramentas de Suporte à Criatividade, propusemos uma segunda investigação focada em explorar a capacidade da ferramenta de auxiliar a criatividade em indivíduos. O estudo de usuário foi realizado comparando quatro versões diferentes de *Musical Brush*, analizando graus distintos de interação e feedback audiovisual. Demonstramos que nossa aplicação apresenta bons resultados no que diz respeito à capacidade de apoiar atributos relacionados à criatividade, tais como: *‘Resultados dignos de Esforço’*, *‘Exploração’* e *‘Expressividade’*. Entre os motivos, o feedback visual através de desenhos tridimensionais se mostrou como principal recurso responsável por tal contribuição.

Palavras-chave: Música, desenho, criatividade, realidade aumentada, ferramentas de suporte à criatividade.

1 INTRODUCTION

1.1 Motivation

Digital tools play a crucial role in the most various creative practices of our daily life, from young children playing on a smartphone app to create simple drawings to professional design artists, who depend on advanced graphical interfaces to accomplish their creative works. In the musicology field – which involves music and technology – since the rise of electronic music sound synthesis, the interest in new ways to express music and new Digital Musical Instruments (DMIs), defined as a "control surface or gestural controller which drives the musical parameter of a sound synthesizer in real-time" (MIRANDA; WANDERLEY, 2006), has continuously increased. The emergence of conferences such as the Creativity & Cognition (C&C), and the New Interfaces for Musical Expression (NIME), first organized as a workshop (POUPYREV et al., 2001) of ACM CHI'2001[1] and bringing together research groups dedicated to exploring themes in interface design, HCI and computer music, illustrate how the topic has flourished.

The relation between digital instruments and creativity culminated in the emergence of a new research branch, known as Creativity Support Tools (CSTs) (SHNEIDERMAN; Ben, 2002; SHNEIDERMAN; Ben, 2007). Derivating from the Human-Computer Interaction (HCI) field, its main concept is the idea that computers have the potential to enhance human creativity (SHNEIDERMAN; Ben, 2002; FISCHER, 2004).

Among the several ways of expressing one's creativity, art representations in the form of paintings have been used by humans since ancient pre-historic times as a form of communication (LI; SONG; GONG, 2013). In this sense, studies point out how the visual characteristic of drawings can yield benefits in terms of helping the conception of new ideas (LUGT, 2005), and act as a facilitator in the design of solutions, (BILDA; DEMIRKAN, 2003). Other creative art forms such as music can benefit from the use of sketches for individuals to express ideas, an example is when highly computer-literate composers use an interactive process that first begins with expressing musical ideas on paper (GARCIA et al., 2011). Since early works (LOHNER, 1986), the combination of music and drawings has been explored mostly on two dimensional (2D) interaction approaches, culminating in the creation of distinct drawing-based musical applications (FARBOOD; PASZTOR; JENNINGS, 2004; MARTIN; TORRESEN, 2019).

[1] <https://sigchi.org/conferences/conference-history/chi/chi-2001-details/>

However, due to the recent and consecutive advances in the research and development of Mixed Reality (MR), the community has progressively explored the use of three dimensional (3D) approaches for musical applications. A few examples include Cave Automatic Virtual Environment (CAVE) immersive rooms (MÄKI-PATOLA et al., 2004), Virtual and Augmented Reality (VR/AR) combined with physical tangibles (POUPYREV et al., 2000; GELINECK et al., 2005; JORDÀ et al., 2007), and Head-Mounted Displays (HMD) with leap motion sensors (ZIELASKO et al., 2015). The works mentioned above demonstrate how wide is the range of possibilities to be explored for artistic purposes using 3D immersive technologies.

Still, regarding drawing-based musical applications, immersive techniques are little explored. Besides, of the present works, most require prior setups and controlled environments for their operation (BERTHAUT et al., 2015). A compelling alternative is the exploration of late advances in the processing power of mobile devices, which have already been used as portable solutions for general AR applications such as navigation (Narzt et al., 2003), exhibition guides (MIYASHITA et al., 2008), and tourism (YOVCHEVA; BUHALIS; GATZIDIS, 2012). This approach benefits from providing a more portable and lightweight immersive experience, also encouraging the application adoption by the general public on account of the massive success of smartphones. Also, mobile phones are seen as having significant potential to be explored as digital musical instruments, once that holds input sensors, signal processing capability, and sound output on a unique device (ESSL; WANG; ROHS, 2008). They also allow spontaneous performances due to their portable characteristics (WANG; ESSL; PENTTINEN, 2008), making them a device with great potential to corroborate the enhancement of daily creativity.

1.2 Research Questions and Approach

In this work, we expand the discussion of novel artistic tools in a different approach: studying the use of 3D interactions and AR technology on drawing-based applications for musical expression, and exploring how these mechanisms can impact on users creativity. Since most of the works in this category only focus on interactions and representations in 2D, we hypothesize that our application can benefit from the extra dimension and immersion capacity, and thus, support creativity in higher levels.

Our research question focuses on the study of using 3D and AR musical applications to improve creativity and is the following:

The use of 3D and AR drawing-based musical applications will enhance users' creativity in comparison to 2D alternatives – the most common solutions – with no immersion?

Despite Creativity Support Tools (CSTs) play a key role in the study of creativity in HCI, most of the studies in this area consist of exploratory prototypes, making it difficult to compare the results from distinct works (FRICH et al., 2019). In an attempt to standardize the used methods, new evaluation methodologies were developed, most notably the Creativity Support Index (CSI) (CHERRY et al., 2009; CARROLL; LATULIPE, 2009; CHERRY; LATULIPE, 2014). Taking these issues into consideration, we contribute to the investigation of creativity enhancement by providing updated results while proposing a novel drawing-based musical tool and investigating its main features. The outcome of this study follows the CSI methodology and can be used for further comparisons with other applications.

The final version of the developed tool, named *Musical Brush*, consists of an artistic mobile application for music and drawing improvisation. The idea follows traditional drawing-based musical tools, in which the generation of musical pieces is done by the creation of 2D drawings. In this work, we make use of AR technology to create and present the 3D virtual drawings in the real environment. *Musical Brush* operates in a standard modern smartphone, and the drawing path is created following the movement of the device. The sound and drawings are generated in real-time simultaneously and both are shaped by several parameters such as the device acceleration and vertical position.

We conducted two user studies, the first one explored the interplay between users and our proposed application. The main idea was to collect feedback regarding *Musical Brush* interface and user experience. From the experiments, we observed that some of the designed interactions were slightly confusing for the participants, thus leading to misinterpretations. Examples include the activation of the delay effect through device shaking movements, and generation of strokes only following the device movement rather than also following finger dragging gestures on the smart screen. While evaluating the controllability features, participants were requested to replicate sample notes using our application. The results show that timbre and pitch were easily mastered by the participants, different from amplitude, whose variations were not perceived by users and presented a high rate of reproduction errors. Participants also highlighted how the visual drawings impacted positively on engagement and expressiveness aspects, leading us to investigate the impact that the tool could have on creativity.

Within the second study, our main focus was to explore how our prototype could impact on the support of creativity. More specifically, we were interested in investigating if the tool was successful in this task, and what were the creativity aspects impacted. We assumed that the developed application would produce a considerable impact on the creativity of users based on the fact that it presented a more immersive and exploratory experience than traditional 2D approaches. In contrast, the 2D version would provide a more convenient experience once that different from the 3D versions, does not require any spatial motion for its functioning. Regarding visual aspects, as reported by user feedback in the first study, the main benefits of the presence of drawings would include a perceived increase of creativity-related aspects, even though the main focus of the tool is musical.

1.3 Objective and Contributions

Considering the context of interfaces for musical expression, we can state that our main goal was the development of a novel drawing-based musical application that could provide a portable and immersive experience for music improvisation and entertainment. Moreover, we focused on analyzing how the developed tool could impact on users' creativity by exploring which different aspects of the tool influence this characteristic. In summary, our main contributions are:

- The design and development of a novel immersive drawing-based musical mobile application, named *Musical Brush*;
- Identification of the relation between the tool features with distinct creativity-related attributes;
- Baseline results to be used for further works and comparisons.

1.4 Structure of this Dissertation

This work is organized as follows. First, related work in the relevant areas is reviewed (Chapter 2). Then, we present *Musical Brush*, our proposed drawing-based musical application, and its technical details and design choices (Chapter 3). Our first user study focused on exploring the tool interface is presented and discussed in Chapter 4. The initial results investigation led us to implement a new user study focused on exploring how the tool can impact users' creativity (Chapter 5). Finally, Chapter 6 summarizes our conclusions and details the upcoming future directions.

2 RELATED WORK

It is no doubt that the advent of computer-generated sounds contributed as a critical player for facilitating and inspiring the emergence of new musical control interfaces. As suggested in Weiser (1991), the current scene moves towards a future of smart objects and ubiquitous computing and the use of devices equipped with several sensors, and capable of producing many parameters for applications will enable almost any artifact, environment or event to produce music (PARADISO; O'MODHRAIN, 2003). Consequently, many musical interfaces based on the most diverse interactions and technologies have been proposed (PARADISO, 1997; LYONS; FELS, 2013). The examples range from simple smartphone applications that explore touch gestures interactions (MARTIN et al., 2016) to alternatives such as simulating the breath input of a flute through the microphone sensor (WANG, 2009) or using head-mounted cameras to keep track of the mouth shape of a performer to control musical parameters (LYONS, 2001).

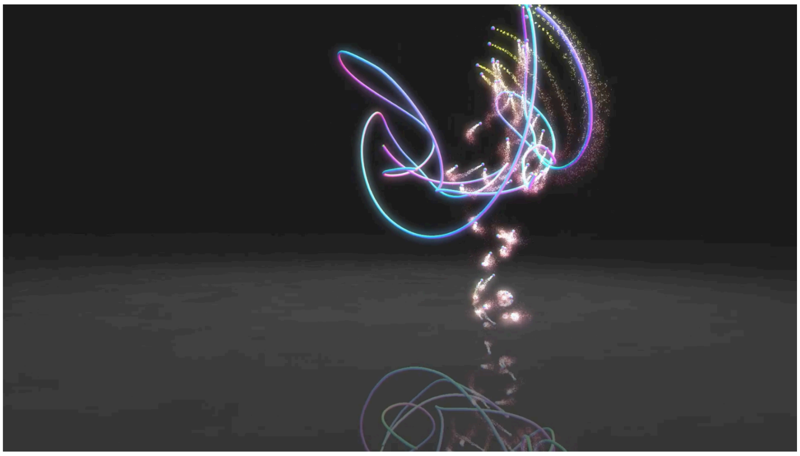
In this chapter, we briefly revise relevant works that present the conception of new interfaces for musical expression. In this sense, we revise the use of gestures to control musical parameters (Section 2.1). Moreover, since our study is particularly focused on the combination of drawing and music using an immersive approach, we also introduce and review works regarding these two subjects (Sections 2.2 and 2.3). Finally, in Section 2.4 we explore existing Creativity Support Tools that focus on music or drawings and review the state of the art regarding this subject.

2.1 Gestural Interaction for Musical Expression

The use of gestural input parameters to control music in real-time has been explored for decades (WANDERLEY; BATTIER, 2000), and the constant advances in sensor technologies make the number of studies within this topic to rise. In an attempt to classify this particular field inside the scope of HCI, Wanderley and Orio (2002) define the topic as *"the simultaneous control of multiple parameters, timing, rhythm"* and *"user training"*.

An early work regarding the use of gestures in real-time to control music is the *Iamascope* (FELS; MASE, 1999). The instrument constantly captures the scene image through a camera and uses the input to control and display graphics content and sound in real-time. By applying image processing to the output image, users' body movements also directly control music and image outputs. In a similar interaction approach, Renaud,

Figure 2.1: In *3DinMotion*, the skeleton of a subject is captured in real time and displayed as an avatar, as well as sonified based on a series of mapping rules. The motion capture dimensions include body posture, space, and time.



Source: (RENAUD; CHARBONNIER; CHAGUÉ, 2014)

Charbonnier and Chagué (2014) bring the *3DinMotion*, a system that uses real-time motion data of one or more subjects to create audiovisual pieces. The system captures the skeleton of subjects and maps them to virtual avatars, which are displayed on a screen (see Figure 2.1). By tracking the position of hands, it is also possible to 'draw' temporary traces in the 3D space. The sonification design relies on a set of layers that are controlled by gestures and can impact sound aspects such as melody, rhythm, or reverberation.

The possibilities regarding new musical controllers are very broad and enable the exploration of many different interaction approaches. The use of other gesture vocabularies than those of a traditional instrument manipulation can result in a less demanding learning process for amateur performers (WANDERLEY; DEPALLE, 2004b). Although this flexibility enables innovative interactions, it presents the downside that most of these alternative interfaces do not reproduce the precision level of traditional instruments (POUPYREV et al., 2000). On the other hand, the design of alternative instruments commonly focuses on expressiveness and leaves accuracy aside (PARADISO, 1997).

Another difficulty related to this wide range of options and possibilities is the lack of a clear set of standards responsible for evaluating the design of musical controllers, making it unclear to determine how well an interface is accomplishing its goals (PARADISO; O'MODHRAIN, 2003). Considering this issue, Wanderley and Orio (2002) propose a classification and a set of important features regarding the usability of musical controller interfaces. The former is consisted on four categories: (i) *Instrument-Like* try to mimic the interface of existing acoustic instruments; (ii) *Instrument-Inspired*, as the name suggests, follows the characteristics of existing instruments; (iii) *Extended Instruments* consist on the use of sensors to augment acoustic instruments; and (iv) *Alternate Controllers*, which are defined by having a design that does not follow any other actual instrument. The latter consists of four characteristics that the authors judge crucial for the operation of musical controllers: (i) *Learnability* refers to the time needed to learn how to control the instrument; (ii) *Explorability* consists of exploring the possible features and the controller's mapping strategy; (iii) *Feature Controllability* is related to the users' perception of actually controlling the musical features by their gestures; and (iv) *Timing Controllability*, refers to the precision that the users can control the temporal performance aspects.

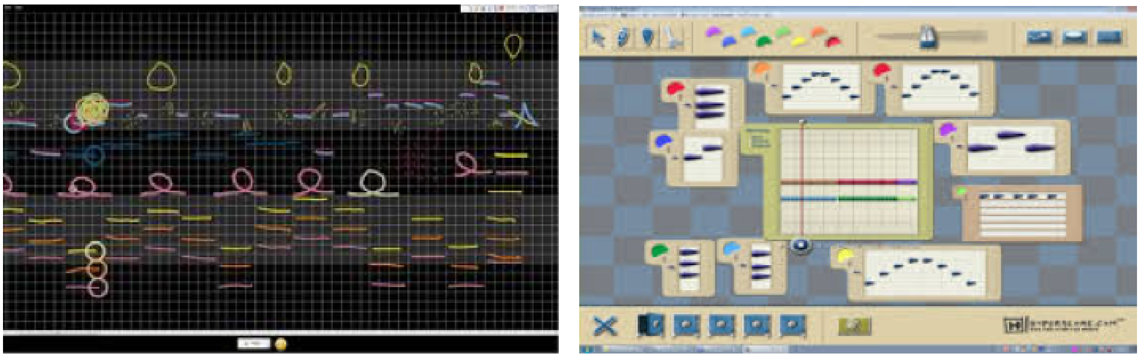
Regarding real-time control systems, Hunt and Kirk (2000) bring a list of characteristics considered crucial for the design of these tools. The authors also mention how the human plays as a key role and participates in full charge of the process, being responsible for controlling several parameters simultaneously. Above, the design features are listed:

- There is no fixed ordering to the human-computer dialogue;
- The human takes control of the situation. The computer is reactive;
- There is no single permitted set of options but rather a series of continuous controls;
- There is an instant response to the user's movements;
- Similar movements produce similar results;
- The overall control of the system (under the direction of the human operator) is the main goal, rather than the ordered transfer of information;
- The control mechanism is a physical and multi-parametric device which must be learnt by the user until the actions become automatic;
- Further practice develops increased control intimacy and thus competence of operation;
- The human operator, once familiar with the system, is free to perform other cognitive activities whilst operating the system.

2.2 Drawing-based Musical Tools

Several tools that combine music with drawings have emerged in an attempt to overcome the limitations of traditional approaches and explore a new way to interact while composing. These works share similar characteristics in terms of providing a more natural interaction and greater support of creative exploration, potentially benefiting from the high

Figure 2.2: Example of performances created using the *Vuzik* (left) and the *Hyperscore* (right) systems. Both applications enable users to create music through two dimensional (2D) drawings. Visual aspects like stroke shapes and colors represent different sound characteristics such as distinct timbres or general effects.



Source: Ichino et al. (2015)

degree of expressiveness provided by the drawing representations. The point here is the utilization of a very intuitive and natural interface: drawing. As mentioned by Thiebaut, Healey and Bryan-Kinns (2008), sketches take an important role in the music improvisation process by enabling free expression of complex ideas. Besides, while acting as a form of visual feedback, improvements are perceived in the understanding of the use of new tools and the perception of controllability (WEINBERG GIL, 2003a).

For professional usage, drawing interfaces usually focus on being a complementary tool or augmenting the usability of particular processes. One example is *Musink* (TSANDILAS; LETONDAL; MACKAY, 2009), which provides users with a system capable of recognizing custom user drawings and interpreting them as music. Similarly, *Inksplorer* (GARCIA et al., 2011) reads drawings in a paper sheet and import them as musical parameters on third-parties music software such as Max/MSP and OpenMusic. In a slightly different way, *Illusio* (BARBOSA et al., 2013) brings an interface that enables users to perform by drawing and associating the custom sketches with live song loops.

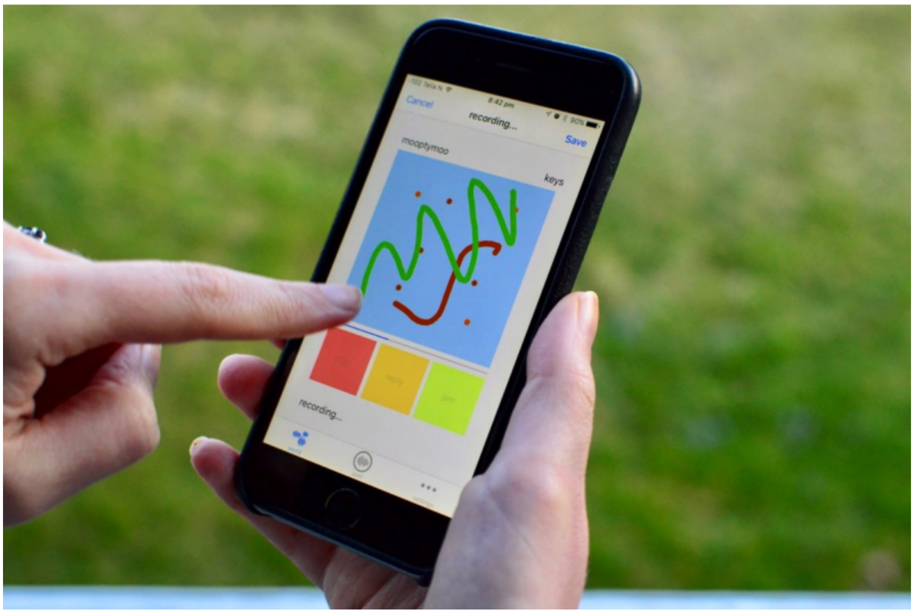
Some musical systems explore the generation of melody lines from simple drawings or trace segments (CHIANG et al., 2012; WU; LI, 2008). A common approach is the transformation of lines and curves drawn into note sequences, possibly varying pitch, timbre, or other sound characteristics. (LOHNER, 1986) presented a compelling early work in this direction. The UPIC System is composed of a digitizing drawing board and a pen that combined, enables users to draw images and generate sound based on the sketches' characteristics. Its intuitive usability and easy assimilation of users in understanding the relation between sound and drawing were responsible for motivating its usage as a pedagogical tool for musical creation (NELSON, 1997). *Articulated Paint* (KNÖRIG; MÜLLER; WETTACH, 2007) enables non-musicians to create musical expressions. The tool uses a physical brush that in contact with a canvas, produces sound based on the characteristics of the stroke produced.

Other works bring more advanced interfaces. *Hyperscore* (FARBOOD; PASZTOR; JENNINGS, 2004), for instance, brings a computer application where users can compose by creating and editing several musical fragments in a whole piece through drawings. Expanding this concept, Ichino et al. (2015) (see Figure 2.2) developed *Vuzik*, proposing the adoption of original painting gestures on a large interactive canvas, and suggesting that music can become more accessible and tangible, and thus more intelligible. Notable features regarding these two works are that, different from the previous examples, the audiovisual pieces can be formed by several layers, thus increasing the degrees of freedom and complexity of the created works. This is possible due to their sketching characteristic, where a piece is composed of several distinct drawing parts and their position on the horizontal axis represent the time they will be reproduced. Making an analogy, this would be similar to a song mix with several layers for different instruments, that combined compose the song. Besides, the extraction of more information from drawings such as the shape of curves and stroke colors are used to improve musical possibilities. A common drawback of the mentioned works is the adoption of one dimension exclusively for time, hence providing only one-dimensional space for the sketching process.

Examples of works that make use of the two dimensions for musical improvisation include *MicroJam* (MARTIN; TORRESEN, 2019) (see Figure 2.3). In fact, this application by Charles P. Marin and Jim Torresen was a great inspiration for the creation of our interface. In this mobile application, users improvise short musical performances by creating drawings on a smartphone screen. The application uses both vertical and horizontal axis to control different musical parameters instead of representing time as a fixed dimension. *PaperTonnetz* (GARCIA et al., 2012) allows users to create melodies by drawing lines in a Tonnetz (see Figure 2.4), which representation is given by a cluster of notes. In this case, time can be inferred by the length of the traces. In *Griddy* (KIM; YEO, 2014), users can explore the musical space through its different layers (see Figure 2.5). The system uses information regarding the background image, the current chording map value and the user drawings as the main inputs to determine the sound output.

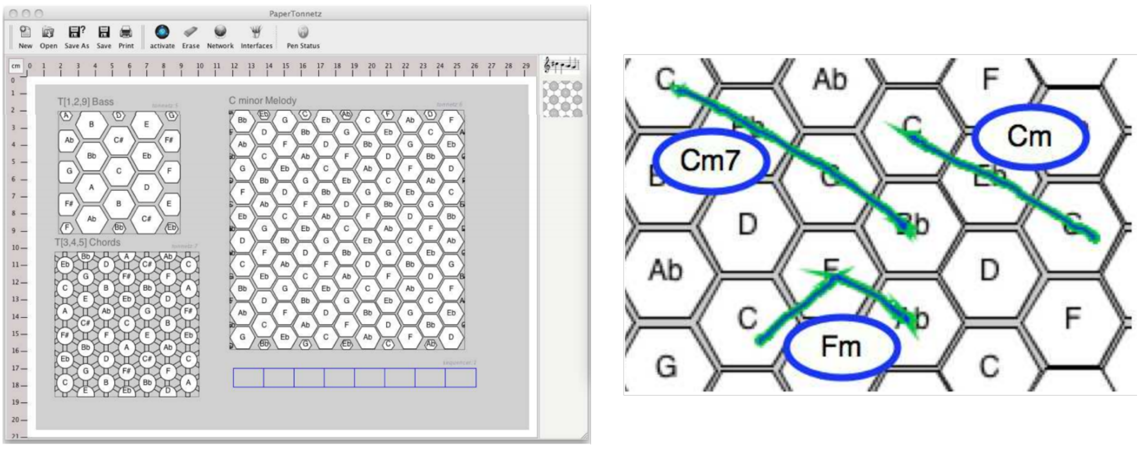
The use of drawings during the sketching process can be seen as a way to assist users in the comprehension of musical interfaces due to its visual feedback. Works like

Figure 2.3: Similar to a social network for music, *Microjam* encourages users to improvise and share performances. Touch gestures on a SmartScreen are used to create the 2D drawings and generate sounds. The pitch is impacted by the horizontal and vertical position of the strokes on the screen, while the timbre is represented by the stroke color.



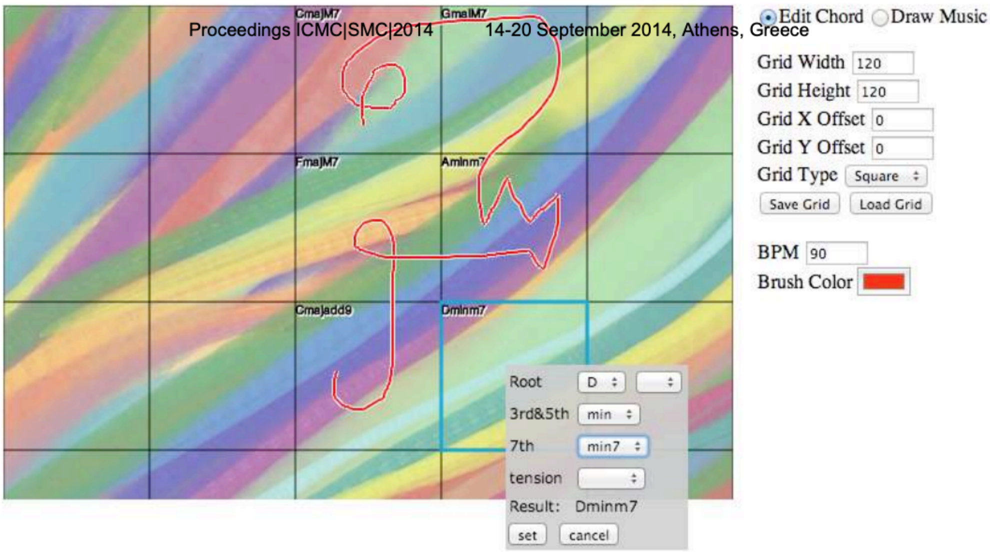
Source: (MARTIN; TØRRESEN, 2017)

Figure 2.4: Left: *PaperTonnetz* main interface representing three Tonnetze and one sequencer. Right: Visualization of drawn paths in the Tonnetz.



Source: (GARCIA et al., 2012)

Figure 2.5: Screenshot of the Griddy prototype. The drawn lines are interpreted and transformed into music in different forms. Characteristics such as the drawing curvature speed determine, for instance, the amplitude and the note to be executed. The grid represents different chords, and when drawing inside its region manipulates the note to be played.



Source: (KIM; YEO, 2014)

(WEINBERG GIL, 2003a) and (BLAINE; FELS, 2003) report the importance of feedback in a composition scenario. The former mentions that some types of visual feedback generated by, for example, computer graphics, can improve the user's sense of control of the tool, while the latter quotes the importance of feedback in the creation of highly responsive systems. The HCI community also highlights the importance of feedback as one of the main pillars in systems usability (DIX, 2004), considered one of the Eight Golden Rules for creating system designs (SHNEIDERMAN; PLAISANT, 2010).

2.3 Music and Immersion

Immersive realities bring unique opportunities for the development of new musical instruments due to the capability of creating scenarios not feasible in the real world. The key benefit related to these technologies is that they can provide entirely new musical experiences not possible with traditional musical instruments or interfaces. Moreover, the exploration of immersive visualizations has been shown to encourage additional abstraction and imagination (SERAFIN et al., 2016). Among the most diverse possibilities, *Virtual Reality (VR)* and *Augmented Reality (AR)* are the ones most explored. The former

Figure 2.6: The Reactable is an electronic musical instrument that explores a tabletop tangible user interface. Users can physically manipulate these physical objects to control sounds and visual outputs.

Source: https://reactable.com

can be seen as a technology that immerses users in a fully artificial environment, while the latter overlays virtual objects in the real-world environment. Regarding AR, Roesner et al. (2014) listed standard properties present in most of the applications, they are as follows:

- Sense properties about the real world;
- Process in real time;
- Provide output information to the user, including via visual, audio, and haptic means, often overlaid on the user's perception of the real world;
- Provide contextual information;
- Recognize and track real-world objects;
- Be mobile or wearable.

Several *VR* approaches have been explored in the creation of new musical experiences (MULDER, 1999; MÄKI-PATOLA et al., 2004; GELINECK et al., 2005). Through a CAVE-like room, *Virtual Air Guitar* (KARJALAINEN et al., 2006) offers a VR guitar version that resembles the real instrument. By varying the distance between the two hands, users can control the pitch, while the movement action of the right-hand is based on

Figure 2.7: Bloom Open Space is an AR collaborative application that represents sounds through floating bubbles in the 3D environment. Through the use of HMD users are able to visualize and create the virtual bubbles.

Source: https://gizmodo.com/the-first-great-iphone-app-grows-up-1823294125

plucking the guitar strings generates sound. AR, on the other hand, was mostly explored with the use of tangibles. The previously cited works (JORDÀ et al., 2007; BERRY et al., 2003), and (POUPYREV et al., 2000; LAURENZO; RODRÍGUEZ; CASTRO, 2009) are some examples that explore physical markers on top of tables. Commonly displaying virtual AR content based on their orientation, interactions such as translation, rotation, and proximity between different markers are used to control the musical features (See figure 2.6). The physical characteristic of these objects naturally contributes to collaboration, since several humans can move and interact simultaneously in a shared environment, being the surrounding space the only constraint.

However, some works explore AR without the use of any tangible. *The Bloom Project* (ENO, 2018), by Brian Eno and Peter Chilvers, represents musical notes through virtual bubbles floating in the 3D environment (see Figure 2.7). Through the use of a MR HMD, users can visualize the virtual content in the surroundings. The application also explores collaboration among several participants. In this case, the virtual bubbles, and the music created individually by each user are shared among the other participants. In *Reflets* (BERTHAUT et al., 2015), performers and spectators experience a mixed-reality (MR) environment for musical performances. In one of the scenarios presented, called *SoundPaths*, performers use a WiiRemote device to draw 3D sound paths that appear on stage and are shown to spectators.

The hype and recent advances in immersive technology are partly responsible for the increasing exploration and conception of new virtual musical instruments. In an attempt to guide the development of these applications, Serafin et al. (2016) proposed a list of design guidelines highlighting important characteristics that should be present on immersive musical systems. Despite focusing only on VR musical instruments, several of the principles can also be addressed in an AR context, they are listed below:

- *Reduce Latency:* highlights the importance of having smooth interactions, where the gap between the different feedbacks such as sound and visual, should be minimized;
- *Make Use of Existing Skills:* this principle is strongly related to Cook's state that *copying an instrument is dumb, leveraging expert technique is smart* (COOK, 2017). As already mentioned, VR/AR instruments can provide new experiences that are not possible in the real world context. However, using some interactions based on real actions can be interesting in the understanding of the tool;
- *Consider Both Natural and "Magical" Interaction*: the author states the use of "magical" interactions, which are defined as actions that do not really respect the real-world constraints;
- *Make the Experience Social*: relative to the characteristic feature of music to allow the sharing of social experiences.

2.4 Creativity Support Tools

Although a complex topic and of hard definition, the interest in creativity and its benefits is expanding, with its importance being observed in many different areas. With works pointing its emphasis on the economic growth and social transformation (NAYLOR; FLORIDA, 2003; FLORIDA, 2005). More specifically, the research of CSTs focuses on the study and development of interfaces that aim not just the productivity of users but also the enhancing of their innovative potential, where its primary goal is to support users on being more creative more often (SHNEIDERMAN; Ben, 2002). The applicability areas of CSTs are very wide, with examples ranging from tools that support storytelling (KIM et al., 2015; SULLIVAN; ELADHARI; COOK, 2018) to the support of ideas brainstorming (WANG; COSLEY; FUSSELL, 2010).

In *Painting with Bob* (BENEDETTI et al., 2014), a CST for digital painting is proposed, focusing on users that rarely engage in arts. The application creates a controlled playground by limiting the range of creative actions that guarantees a minimum degree of quality for novices to experiment with painting. On another work, Griffin and Jacob (2013) proposed a novel adaptive instrument to make music improvisation available to individuals regardless of music expertise. Results presented from user evaluations reveal that the proposed interface is capable of boosting creative abilities.

In a slightly different approach, *MoBoogie* (HALPERN et al., 2011) uses movement sensors present in an Android mobile device to manipulate and shape music characteristics such as melody, bass, and drums. The application, designed to foster experiences in creative expression for children, presents a screen divided into three tracks. The tracks correspond to each of the three accelerometer's axes (x, y, and z) and the sound produced is modeled by the corresponding device movements. Results indicate that the application was successful in engaging users to be creative while moving and performing music. In *Musink* (TSANDILAS; LETONDAL; MACKAY, 2009), the authors explore the role that paper plays in creativity and how an interactive paper approach can support the creative design process in a musical composition tool that uses augmented drawing.

Among the main characteristics of CSTs, Shneiderman et al. (2006) highlighted that these interfaces should provide strong support in forming hypotheses, quickly assessing different alternatives, improving understanding through visualization, and better-disseminating results. The same work also proposes a list of twelve principles that aim to guide the development of new CSTs. These patterns are presented as follows:

- S1) Support exploration;
- S2) Offer low threshold, high ceiling, and wide walls;
- S3) Support many paths and many styles;
- S4) Support collaboration;
- S5) Support open interchange;
- S6) Make it as simple as possible—and maybe even simpler;
- S7) Choose black boxes carefully;
- S8) Invent things that you would want to use yourself;
- S9) Balance user suggestions with observation and participatory processes;
- S10) Iterate, iterate—then iterate again;
- S11) Design for designers;
- S12) Evaluate your tools.

2.5 Summary

The exploration and conception of new musical interfaces is an ever-growing area since the rise of electronic music. Moreover, the advances in technology bring a wide range of possibilities that were not explored before, leading to a direction where almost any object will be capable to be used as a music producer (WEISER, 1991; PARADISO; O'MODHRAIN, 2003). Following this scenario, new conferences specialized in this topic have been created. An example is the NIME conference, which was created from a special CHI workshop (POUPYREV et al., 2001) branch and among its main themes, explores interface design, HCI and computer music.

The development of tools with different approaches can impact distinctly the enhancement of people's creativity for specific artistic tasks. Previous works regarding drawing-based musical applications explored the production of drawings making use of different 2D planes such as virtual canvas (FARBOOD; PASZTOR; JENNINGS, 2004; ICHINO et al., 2015), and smartphone touchscreens (MARTIN; TORRESEN, 2019).

Within this work, we expand the discussion to a different approach: the use of 3D motion interactions and AR technology to represent drawings in a mobile immersive experience. In theory, the freedom provided by this extra dimension combined with the AR immersive experience would corroborate to the enhancement of creative-related attributes. As mentioned above, most of the previous works mainly focus on 2D approaches, limiting the interaction possibilities. Regarding immersive interfaces, using tangibles to control musical parameters (JORDÀ et al., 2007), or re-creating real instruments on a virtual environment (KARJALAINEN et al., 2006) are common use cases. Nevertheless, the use of tangibles limits the experience to certain places and requires a prior setup for its usage. Moreover, the exploration of drawings combined with music on immersive experiences is still little explored (BERTHAUT et al., 2015).

3 MUSICAL BRUSH - SYSTEM DESIGN

3.1 System Overview

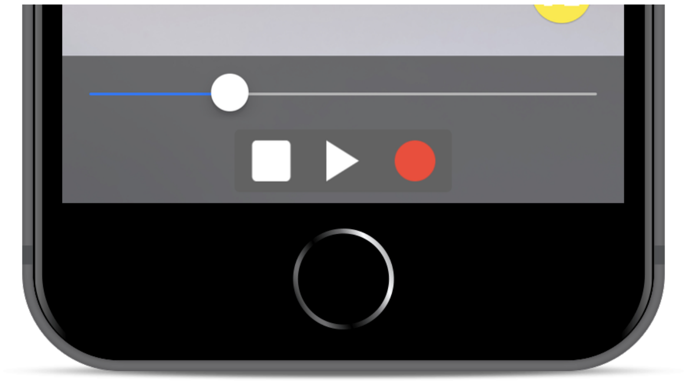
The application we developed in this work, named *Musical Brush*, is currently a mobile iOS artistic application and allows novices to improvise sounds while creating drawings in AR. The application essential operation consists of mapping different user interactions into sounds and drawings. In a similar gesture mapping concept to a Theremin, the generation of sound and drawings is controlled by three-dimensional movements. By moving the smartphone device, the application creates a virtual 3D stroke along the path taken. The drawing strokes will permanently represent the performance melody structure. Both sound and visual outputs are shaped and controlled by several pre-defined interactions.

Through the use of AR, the visual strokes created in real-time by *Musical Brush* are represented in three dimensions in the real environment. The melodies are represented by colored traces settled in the air whose visual appearance such as color, and thickness are strongly connected with the sound produced. By requiring only a smartphone for its operation, the app allows the creation of a very expressive, interactive, and immersive experience in a portable light-weighted setup. Parameters extracted from smartphone embedded sensors such as the camera, accelerometer, and pressure sensors are used to shape the audiovisual output. Sound characteristics such as amplitude, timbre, and reverberation effects are some examples. The same happens for visual aspects such as stroke colors, animations, and thickness. A demonstration video of the *Musical Brush* is available online.[1]

Differently from previous 2D drawing-based musical tools, *Musical Brush* does not restrict users in creating drawings on a predefined limited canvas. On the contrary, by exploring the real environment as its 'drawing board', it provides an infinite number of movements and illustrations possibilities. However, this greater freedom of expression enabled by using the device's 3D movement to draw makes the tool physically more demanding for users than a simple 2D version. For example, to reach certain sound frequencies users must raise or lower the device considerably in space to reproduce the desired sound.

[1] <https://vimeo.com/457539014>

Figure 3.1: Component used to switch among the different execution modes of the application. From the left to right, the buttons' purposes are respectively: stop execution, pause execution and start recording a new track. The slider bar represents the current timestep of the performance and advances with along with the time while playing.



3.1.1 Execution Modes

Due to its musical nature, the application operates in a way where it is possible to compose small melodic performances. Therefore, the app contains on its interface a component used to control and manipulate the performance execution, as shown in Figure 3.1. This small component handles the control between the different execution modes, labeled as *Practice Mode*, *Composition Mode*, and *Playback Mode*. Details regarding the different modes are presented below.

The *Practice Mode* objective, as the name suggests, is to enable users to test different ideas and learn how to use the application. In this mode, the actions made by users are only temporary, not being saved to the final performance. It is also the current starting state of the application, and while on it, the generated virtual strokes vanish a few seconds after its creation. The *Composition Mode*, on the other hand, preserves permanently the actions made by the users. This mode is reachable after pressing the red button present in the execution control component (Figure 3.1). After the trigger, a three seconds count down will start, and subsequently, the user will have eight seconds to record a new *'Track'*.

Here, we introduce our definition of *'Tracks'*. In our design, the sketching process is incremental, consisting of several individual tracks. In an analogy with a song, it would be similar to several individual instrument tracks that together constitute a song. Each of these tracks is composed of a sequence of drawings and sounds. After a new track is created, users can choose to save it to the final piece or delete it, also being possible to recreate parts of the recently created track after a certain point in time.

Finally, the *Playback Mode*, which is achievable through pressing the play button in the execution control component, and results in the reproduction of the current saved performance. Along with starting to reproduce the sound, the virtual strokes, which are initially slightly transparent, will start to be gradually colored as the playback executes. Moreover, the slider bar present in the control component represents the current time step of the performance, advancing in sync with the execution time, and if manually interacted will modify the current execution timestep. Figure 3.2 brings some examples of performances created with Musical Brush.

3.1.2 Design Rationale

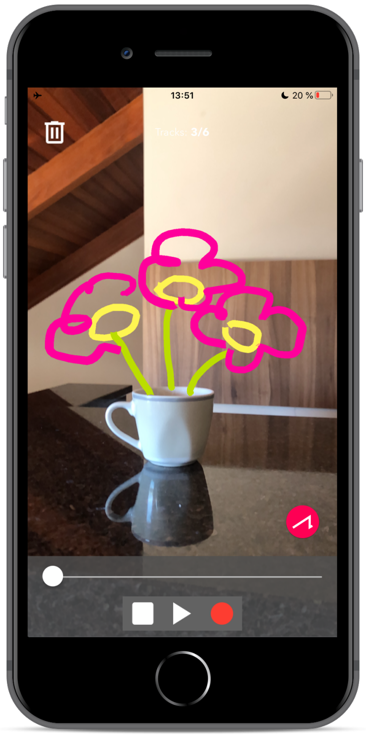
Here, we review the frameworks and guidelines that were relevant during the development stage of the proposed work. Examples include patterns for the conception of new CSTs and design principles on using gestural interactions for musical expression.

Among the twelve guiding principles proposed in (SHNEIDERMAN et al., 2006) for the development of new CSTs, and already listed in Section 2.4, we see a relevance for our context in the following points: S2) Low threshold, high ceiling, and wide walls; S6) Make it as simple as possible, and S12) Evaluate your tools. S2 suggests a low entry barrier for novices to use the tool while supporting more sophisticated levels and a range of possible explorations. S6 reiterates that the tool should be of easy manipulation, while S12 highlights the importance of evaluating and improving the tools.

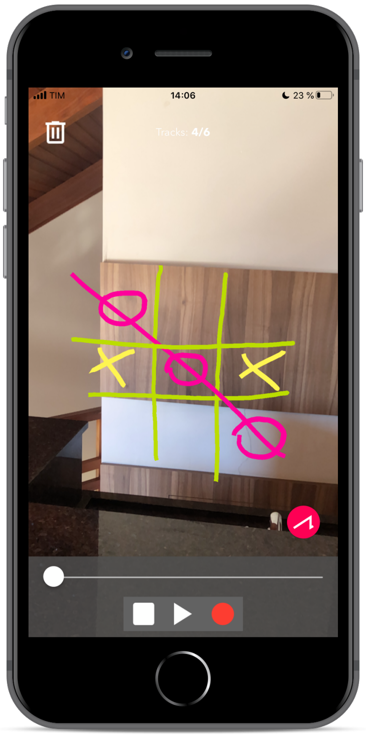
Regarding the use of gestures to control music, our tool can be classified as an *'Alternate Controller'*, which design does not follow the behavior of any existing instrument (WANDERLEY; ORIO, 2002). On another work, (HUNT; KIRK, 2000) brings crucial characteristics for the design of real-time controllers, of which we can highlight the following: *"The human takes control of the situation. The computer is reactive"*; *"There is no single permitted set of options but rather a series of continuous controls"*; *"Instant responses to the user's movements"*; *"Similar movements produce similar results"*; *"The control mechanism is a physical and multi-parametric device which must be learned until the actions become automatic"*, and *"Further practice develops increased control intimacy"*;.

Concerning the use of immersive technologies for musical purposes, Serafin et al. (2016) bring attempts to guide the conception of Virtual Reality (VR) interfaces. De-

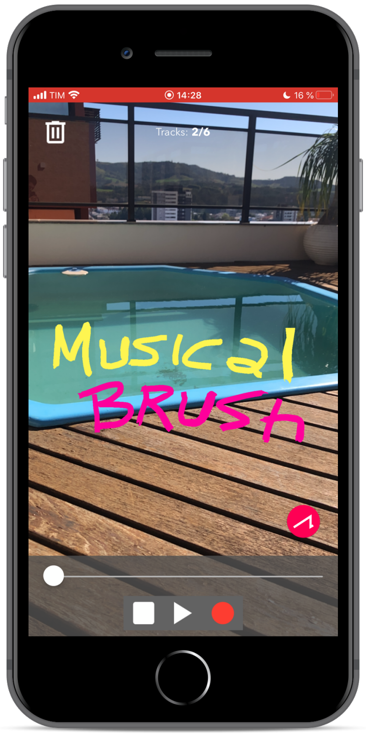
Figure 3.2: Examples of multitrack performances created using Musical Brush. The colored virtual strokes represent the melody of the piece.



(a) <https://vimeo.com/450202909>



(b) <https://vimeo.com/450203242>



(c) <https://vimeo.com/450203652>

(d) <https://vimeo.com/450492360>

spite focusing exclusively on VR musical instruments, some of the principles can also be addressed in an AR context: P1) *Reduce latency*, this principle is connected to having smooth interactions, where the gap between different feedbacks such as sound and visuals should be minimized; P2) *“Make Use of Existing Skills"*, this principle is firmly related to Cook’s state that *copying an instrument is dumb, leveraging expert technique is smart* (COOK, 2017). As already mentioned, VR/AR instruments can provide new experiences that are not possible in a real-world context. However, using some interactions based on real actions can be interesting in the understanding of the tool; and P3) *“Consider Both Natural and ‘Magical’ Interaction"*, this principle highlights the importance of having actions that do not respect the real-world constraints and may cause a positive impact on users.

Concerning guidance patterns for the development of CSTs, Shneiderman and Ben (2007) suggest four design principles: P1) Support exploratory search; P2) Enable collaboration; P3) Provide rich history-keeping; and P4) Design with low thresholds, high ceilings, and wide walls. On *Musical Brush* context, we find P4 to be the most relevant, suggesting that CSTs should aim to be easy for novices but yet provide ambitious functionality that experts need. While designing our prototype, we analyzed these design patterns, as well as the twelve principles proposed by Shneiderman et al. (2006) and already cited in Chapter 2.

3.2 Mapping Strategies

The combination of gestural interactions with sound and visual components was explored in many works as already detailed in Chapter 2. Therefore, the development of intuitive designs is necessary. Nowadays, the range of gesture-based applications controlling sound and visual aspects extends beyond the musical scenario to gaming applications (RASAMIMANANA et al., 2012), and sonic interactions where the use of sound feedback can help the movement performances during rehabilitation (FRANÇOISE; Jules, 2013). This section presents some characteristics regarding common mapping strategies. Moreover, we detail the design of our visual and sound mapping.

3.2.1 Sound Mapping

A crucial step while designing a musical controller is the definition of the *mapping*, a term used to describe the relationship between the instrument input interactions and the sound output (HUNT; KIRK, 2000; HUNT; WANDERLEY, 2002). Typically, the input consists of gestures executed by a human performer that will control the generated sound through a set of mapping configurations. Regarding the different possible approaches for the mapping, some works propose classifications that take into account the relation between the number of input controls and the number of output parameters that each mapping strategy uses (ROVAN et al., 1997; HUNT; WANDERLEY, 2002). The authors define three main categories for these relations, and although not using the same names, they have the same meaning. The definitions and explanation are as follows:

- *One-to-One Mapping*, where each input controls one sound parameter;
- *One-to-Many / Divergent Mapping*, where one input control many aspects of the sound;
- *Many-to-One / Convergent Mapping*, where several inputs are needed to control one only parameter.

Many instruments use more than one approach at the same time for dealing with different aspects of its working functionalities. In a violin, for example, several input parameters such as the performer finger position on the string, and the pressure applied to the bow, are required to control only one output aspect as the sound pitch. This relation characterizes a *Many-to-One / Convergent Mapping*, where the combination of different parameters impacts one output value. On the other hand, if we analyze the impact of the bow in this instrument, we can notice that it is directly connected to more than one output parameter, influencing distinct aspects such as volume, timbre, and articulation. This last scenario characterizes an example of a *One-to-Many / Divergent Mapping* in this classification.

Finding an intuitive and satisfactory mapping design that is engaging and intuitive for both novel and inexperienced performers is an essential part of this work. Performing on simple *One-to-One* interfaces tend to be learned easier if compared to more complex mapping strategies, yet, this more straightforward approach can give an impoverished experience to both performers and listeners (HUNT; KIRK, 2000). For this reason, the tradeoff between simplicity and engagement must be taken into account when designing a mapping strategy. Moreover, the synergy between the generated output and the input gestures in a system plays a vital role for a better understanding of how the instrument operates: *direct correlation between gesture and sound reduces cognitive processing load and enhances performance* (KEELE, 1973).

Several different techniques have been considered before achieving our current sound mapping approach. We acknowledge that conceiving an action-sound relationship for a musical controller is not an obvious task (WANDERLEY; DEPALLE, 2004b). Furthermore, we do not aim to base our mapping strategy on any existing traditional musical instrument, designing a unique experience for users in the process of music creation. Due to the intention of implementing an interface where not only skilled musicians but also beginners could operate, we focused on implementing a simple and direct sound mapping approach, as suggested by Wessel (1979). Therefore, the application's sound mapping consists of an *explicit mapping*, defined by Hunt and Wanderley (2002) as one-to-one relationships between input gestures and output sounds. The set of interactions is listed as follows:

Sound Generation: the generation of sound is the most essential characteristic of a musical controller. In *Musical Brush*, the simple interaction of holding the screen pressed will result in producing tones. This outcome will be shaped by all the remaining interactions explained below and will be produced as long as the touch interaction continues.

Pitch Control: pitch, in music theory, is a property of sound that denotes how high or low a note is played. In our mapping design, this characteristic is controlled by the smartphone vertical position. Moving the device vertically up in the 3D space will produce high-frequency notes, whereas the opposite will result in more bass melodies. To achieve this design, we considered studies showing that users tend to relate the changes in the vertical axis to variations at the frequency of sounds (NYMOEN et al., 2010).

Amplitude Control: the term amplitude refers, in physics, to the fluctuation of a wave from its mean value, more specifically to the musical context, the amplitude represents the loudness of sounds. In our mapping design, this characteristic is controlled by users through the applied force on touch interactions. This feature was designed following (HUNT; WANDERLEY, 2002) guideline: *"Energy is required for amplitude"*. The constructed relationship between amplitude and energy from input gestures is directly proportional, where more intense touch pressures will result in louder sounds, while smoother pressures produce lower melodies.

Timbre Control: Timbre, also known as *'tone color'* refers to the perceived tone quality of notes. This characteristic is what enables us to differentiate among distinct types of sound productions such as choir voices, wind and string instruments, or percussion. In our current application, it is possible to pick four pre-fixed timbres, expressed by simple waveforms: Sawtooth, Sine, Square, and Triangle. We decided on simple waveforms for our initial prototype, but more complex tones can easily be implemented for further studies.

Delay Effect: the delay effect is characterized by an audio signal that is played repeatedly after a short period. These repeated signals are reproduced with less and less amplitude as time passes, mimicking an echo. Our mapping enables the activation of this reverberation effect by shaking the phone abruptly. After activated, the effect lasts for 3 seconds and modifies the sound generated.

3.2.2 Visual Mapping

Although less important than the *Sound Mapping* in the context of a musical controller, the mapping of user inputs to visual graphics defined here as *'Visual Mapping'* also plays a key role in the designed application, as reported on some works. Weinberg Gil (2003b) stated that the use of computer graphics as feedback on musical composition tool systems can enhance the users' sensation of controllability. Besides, Serafin et al. (2016) describe the importance of visualization in immersive systems as a way to aid players' performances.

Systems that use multimodal outputs, however, should concern about the synergy present among these different senses. Humans do perceive simultaneously several different modes of sensory input. We can, for example, see a car moving in the street while we hear the noise of its engine. These multiple senses act in an additive way, and for this reason, the match between them is necessary to prevent a feeling of disorientation on users. Regarding this issue, among the design principles for computer music by Wang (2014), one in particular defends that sound and graphics should conform – *"Design sound and* *graphics in tandem: neither should be an afterthought; seek salient mappings"*. This audiovisual experiences can also be used to improve not only the understanding of the performers but the audience itself (PARADISO, 1998).

In *Musical Brush*, the main visual element corresponds to the 3D virtual strokes. Their creation depends on the user's touch interaction on the screen, and the generated trace will follow the device movement, thus creating a path behind its progress. These strokes, similar to the output sound, are also shaped concerning the features extracted detailed in Section 3.4. Below, we describe how the different interactions affect the visual components present in our tool.

Trace Color: the color displayed in the trace represents the chosen timbre at the time of its creation. The currently used colors are blue, red, yellow, and green, and correspond respectively to the following waveform tones, sine, sawtooth, square and triangle (see Figure 3.3a).

Trace Thickness: the touch pressure on the screen that controls the amplitude in the *Sound Mapping* is also responsible for defining the trace thickness. In our design association, greater pressure will result in thicker traces (see Figure 3.3b).

Trace Animation: the natural behavior of the virtual traces created by the application is to remain static where arranged. However, once the accelerometer detects a very abrupt acceleration of the device, it will trigger the delay effect on the *Sound Mapping*. In addition to this, the visual representation of the traces will also be modified regarding this event, being animated with shaking movements while this effect is activated (see Figure 3.3c).

3.3 Technical Details and Choices

Musical Brush is a prototype application for iOS devices. For its implementation, we used the Swift language rather than Objective-C due to all the benefits that the first provides in terms of facilitating the development process (GARCÍA et al., 2015). The selection of the technology used to present the AR experience to the users was also carefully analyzed. Existent works commonly explore the creation of music on AR environments through

Figure 3.3: Example of the different visual mapping characteristics present in *Musical Brush*. The Figures (a), (b), and (c) bring, respectively, representations of different trace colors, thickness, and animations.

(a) The color displayed on each stroke represents a different waveform timbre. (Green: triangle; Yellow: square, Red: sawtooth; Blue: sine)

(b) The thickness of the stroke is connected to the sound amplitude. The thicker the stroke, the louder is the sound it represents.

(c) When activated, the delay effect visual feedback causes the strokes to continuously shake. (This effect is better perceived through video)

the use of HMD (ZIELASKO et al., 2015; ENO, 2018) or tangibles (POUPYREV et al., 2000; JORDÀ et al., 2007). In our understanding, however, these technologies would not match the level of freedom desired for *Musical Brush*. Furthermore, our ambition for portability and general use adoption contributed to considering a mobile application with a handheld display as the most appropriate choice. We are thus making use of the embedded sensors present in a modern smartphone to create a smooth and straightforward AR experience.

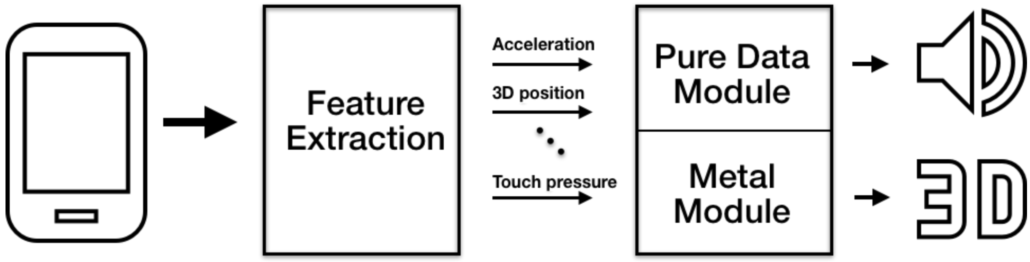
We opted for using the ARKit[2] framework to integrate the camera and motion features and produce the augmented reality content on our application. By taking advantage of the camera image together with the environment tracking system, it is possible to detect and retrieve information concerning the 3D coordinates space that the user inhabits, and thus enabling the placement of virtual content. Moreover, the low-level Metal[3] Application Programming Interface (API), which shows better performance on draw-calls per frame if compared to OpenGL-based solutions (SCHIEWE; ANSTOOTS; KRÜGER, 2015), was used for element graphics rendering purposes.

Regarding sound generation, the application uses *Pure Data (PD)*[4] as synthesizer.

---

[2]<https://developer.apple.com/arkit/>
[3]<https://developer.apple.com/documentation/metalkit>
[4]<https://puredata.info>

Figure 3.4: Sound and visual mapping flows. The device sensors are responsible for extracting the values of the features such as acceleration and 3D position in the environement. Then, the corresponding values are forwarded to both the Pure Data and Metal modules, where they will, respectively, be responsible for generating the sound and graphics content.



PD is an open-source visual programming language used for interactive computer music and sound manipulation and as detailed in Subsection 3.2.1, plays a key role in the process of sound mapping by transcribing the input parameters into sound output. Although only simple waveforms are currently being used for the different timbres in this project, the use of PD allows easy incorporation of more complex sound textures for future versions of the application, including physical synthesis and sample-playback based patches. Figure 3.4 illustrates how the extracted features are forwarded to the PD module in real-time. There, the collected parameters are combined with oscillators to shape and create a sound by manipulating audio signals. Every particular timbre has a different treatment once each tone requires distinct signal manipulation. Subsequently, the *Digital Audio Converter (DAC)* receives the resulting calculations and converts them into sound output.

3.4 Feature Extraction

The feature extraction, in this work, is characterized by the process of tracking the interactions performed within the interface and extract features that are important for the operation of the system. This step is crucial for the sound and visual mapping of our application, once the outputs and input interactions are strongly connected. In *Musical Brush*, we make use of the several sensors present in a modern smartphone to trigger and control these effects. This approach, defined by Wanderley and Depalle (2004a) as *Direct Acquisition*, is well established in music controllers, and its usage is characterized by the adoption of one or more sensors to monitor the performer's actions in an independent way.

So far, in our application, we have been tracking attributes related to the smartphone movement and position in the 3D space, as well as interactions with the device's touch screen itself, all attributes are currently being extracted at a rate of 60 times per second. The list of extracted features is shown below:

- *On-screen touch detection*: this action is triggered when the user touches and holds the screen pressed, the extracted value is a boolean value that indicates whether the touch action is true or false.
- *On-screen touch pressure*: characterized by the on-screen applied force on touch events, the extracted value is a float number that ranges from 0 to 1 and represents the magnitude of this force.
- *3D coordinates*: the smartphone's current position concerning the 3D plane. This feature is extracted through using ARKit standard library, where the relative x, y, and z locations are calculated using the device's camera to detect points of interest present in the environment. After detecting a horizontal plane, this will be considered the "floor" of the scene.
- *Absolute acceleration*: this measured value is extracted through the use of the device's accelerometer. The generated output is a number that indicates the momentary acceleration.

3.5 Summary

A novel AR drawing-based musical app was proposed to circumvent the previously observed limitations concerning poor portability and laborious immersive configuration of immersive environments. Moreover, the application explores 3D motion interactions, characteristic that lacked on previous 2D static drawing-based interfaces. The *Musical Brush* prototype only requires a smartphone for its operation, and the sound and 3D visual outputs are based on user-device interactions. The following chapters report the two user studies conducted within this work. The first is detailed in Chapter 4 and consists of an exploratory study where we mainly explore how the users interact with the application, collecting feedback regarding usage, interface, and interaction issues. The second study is described in Chapter 5 and focuses on exploring how Musical Brush can impact on supporting the creativity of users.

4 USER STUDY I - INTERFACE EVALUATION

This chapter presents the details regarding our first exploratory study of *Musical Brush*. The experiment consisted of an assessment of our initial application through a pilot study conducted with a total of seventeen subjects to better understand the interplay between user and application. The main goal was to collect overview feedback regarding usage, interface, and interaction issues. Thus, we focused on the exploration of relevant features for musical controllers : *'Learnability', 'Explorability', 'Feature Controllability'*, and *'Timing Controllability'* (ORIO; SCHNELL; WANDERLEY, 2001).

This study was held at the University of Oslo (UiO), in Norway, during an academic exchange performed throughout the master's degree.

4.1 Experiment Design

4.1.1 Tasks

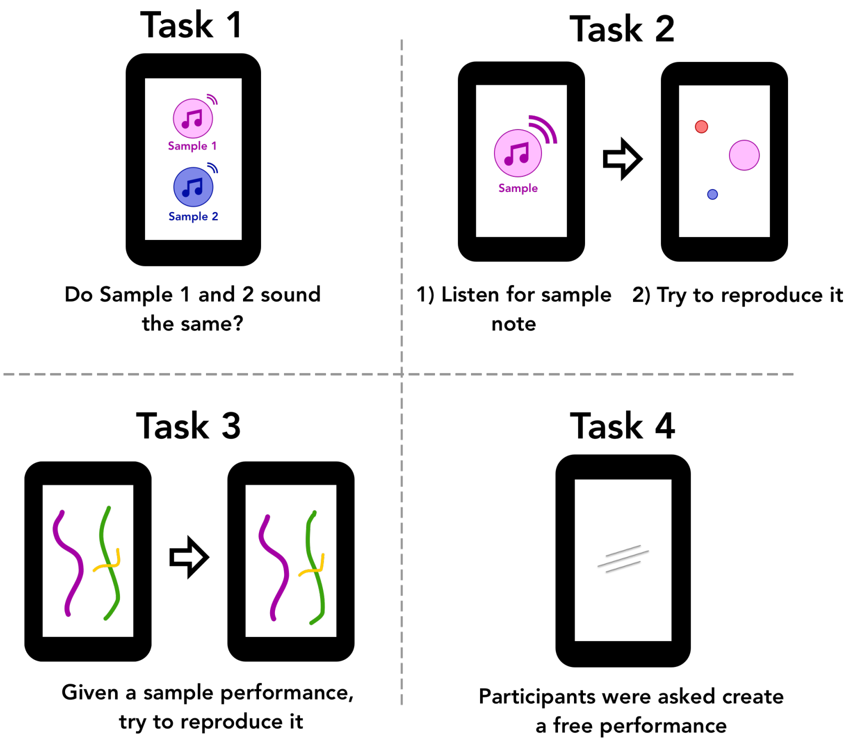
The tasks applied in the experiment are summarized and detailed below.

Task 1 - *Auditory Perception Task* (T1): In this first task, the subjects were presented to an interface containing two distinct buttons, each of them producing a musical note when pressed. The objective here was for participants to distinguish whether the two samples produced the same sound regarding timbre, amplitude, and pitch.

Task 2 - *Auditory Reproduction Task* (T2): In this task, participants were requested to use the developed application to replicate a given musical note. The original application interface was slightly modified by introducing a new button that, when pressed, reproduced the sample note. Users were able to listen to the sample note as many times as needed.

Task 3 - *Performance Reproduction Task* (T3): In a more challenging variation of the previous task, participants were requested to replicate a given performance containing one or more tracks. The example performance to be replicated was displayed in front of the user, who could walk through and examine it from different angles. As soon as the participant begins the replication process, the original copy disappears.

Figure 4.1: *Task 1:* subjects were asked whether the two samples were equal or not. *Task 2:* after listening for a sample sound, users were asked to try to reproduce it using Musical Brush. *Task 3:* participants were requested to replicate a sample performance. *Task 4:* creational task, users were requested to create a free performance.



Task 4 - *Free Performance Task* (T4): In this last task, the participants were free to create their performances, without any restrictions in the number of tracks or limits regarding time.

4.1.2 Questionnaires

The questionnaires applied in this pilot study are summarized here. *(All applied questionnaires are attached to the end of the document)*.

The *Intake Questionnaire* (Q1) (see Appendix A) was used to collect demographic information from the participants, as well as previous experience regarding music practice.

The *Task 2* (Q2), *Task 3* (Q3), and *Task 4* (Q4) Questionnaires (see Appendix B) were applied after participants completed tasks T2, T3 and T4, respectively. The questions of the three questionnaires focused on exploring the difficulties faced by the participants during the execution of each particular task.

Finally, the *Overall Questionnaire* (Q5) (see Appendix C) consists of questions regarding the experience of using the application in general. Here, the questions focused on exploring the four relevant aspects for musical controllers highlighted in Orio, Schnell and Wanderley (2001): *Learnability, Explorability, Feature* and *Timing Controllabitily*.

4.1.3 Subjects

The study population, recruited through volunteering from both the Informatics and Psychology Institutes at UiO, was composed of seventeen subjects (10 males and 7 females) with age ranging from 20 to 62 (29.94 ± 10.3). Regarding previous music knowledge, 47.1% of the participants reported having at least three years of prior practice, 23.5% between 1 and 3 years, and 29.4% had no previous experience.

4.1.4 Protocol

The experiment consisted of a pilot study conducted with a total of seventeen volunteers and no previous knowledge or experience in any specific area was required for participation. The study took place in the Informatics and Psychology Institutes at the University of Oslo (UiO). All rooms used for the experiment shared the same characteristics, with around 18 square meters of free space, thus allowing the free movement of the participants. Furthermore, the device chosen for the experiments was a 5.5 inch-display iPhone 8 Plus smartphone running iOS 12.1.2.

The experiment begins with a general overview concerning the study objectives and what we expect for the participants to do during the tasks. After accepting the study terms and conditions, the participants start by answering to Q1. Next, an introduction to the developed application (*Musical Brush*) was performed, where the volunteers learned its essential operation, characteristics, and controls. During this stage, participants were encouraged to explore the application for four minutes and become familiar with its features.

After this first introductory session, participants were invited to perform, as accurate as possible, each of the four tasks detailed in Subsection 4.1.1. Individually, each user performed repeated trials for each task: five for T1, five for T2, three for T3, and once for

T4. None of the tasks had any restrictions regarding time limits or a maximum number of repetitions that a sample could be played for their fulfillment. The questionnaires Q2, Q3, and Q4 were applied after completing T2, T3, and T4, respectively. At the end of the experiment, participants were asked to respond to Q5, as well as encouraged to verbally share ideas and thoughts with the interviewer. In general, each experiment took no more than 30 minutes to complete, and, as a form of gratitude, chocolates were offered to the participants.

4.2 Results

This section presents the results obtained from our first exploratory study. The main focus was to collect potential insights regarding application usage, interface, and interactions. Moreover, we aimed to understand the user's opinion regarding particular characteristics of the developed application such as musical controllability, enjoyability, and audiovisual outputs. Objective data from the questionnaires were analyzed by calculating the average (μ) and standard deviations (σ) for each topic, and are reported here as $\mu \pm \sigma$.

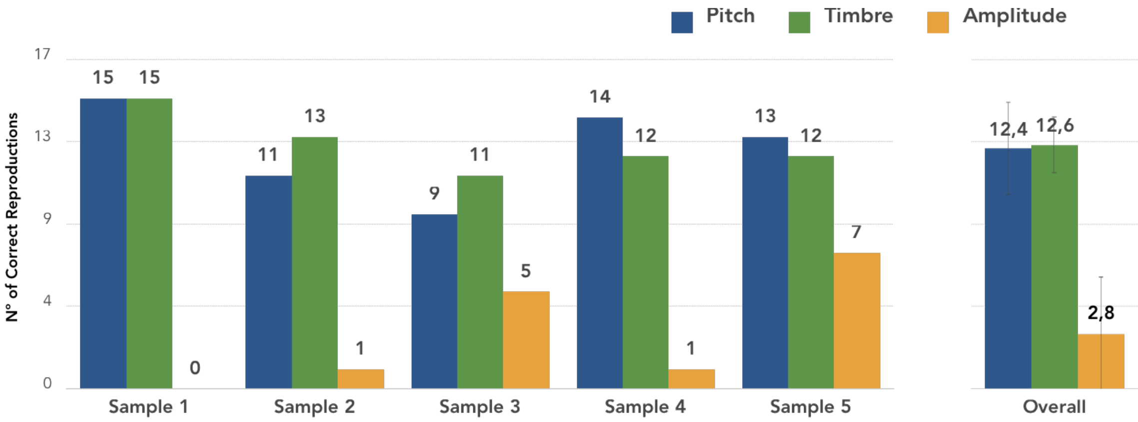
4.2.1 Objective Evaluation

Despite the participants' different levels of musical experience, general results from T1 were favorable concerning their ability to distinguish different musical notes. From a total of 5 trials, the average number of correct answers, that is, if the participants were able to distinguish if the played sounds were equal or distinct, was notable (4.7 ± 0.46).

During T2, pitch, amplitude, and timbre were measured as the participants attempted to reproduce sample notes. Since the first two characteristics are continuous values, their discretization was necessary to make feasible the comparison with the original sample notes values. Pitch was discretized using a threshold of 40 cent (MIDI scale), according to the music cognition study in Schramm, Nunes and Jung (2016). Concerning amplitude, we used a threshold of 3 dB (*Just-noticeable Difference – JND*), as recommended by Rossing (2007) in situations of "real world" measurements, including listening devices such as headphones.

A detailed view of the results of T2 is shown in Figure 4.2. The first five graphs (from left to right) represent the total number of participants (out of 17) able to correctly

Figure 4.2: Results from T2, showing the number of participants able to reproduce the pitch, timbre, and amplitude for each of the tested samples. Pitch (blue) and timbre (green) were the sound characteristics with the highest correct reproduction rate, while amplitude (yellow) presented a very low reproducibility. The five first graphs (from left to right) bring the result individually for each tested Sample, while the last brings the average results.



reproduce the pitch, timbre, and amplitude for each of the five samples. The graph on the far right summarizes the average results calculated from all the five samples in the task. From the results we observe that the samples timbres were correctly reproduced, on average, in 74.11% of the times (12.6 ± 1.5), followed by pitch, correctly reproduced in 61.18% of the times (12.4 ± 2.4), and amplitude, correctly reproduced in only 16.47% of the times (2.5 ± 3.0).

4.2.2 Subjective Evaluation

The participants' subjective impressions of the application were obtained by analyzing the observations and opinions recorded on the questionnaires. A summary containing the results of the evaluation is presented in a complementary way through Table 4.1.

The objective results presented in Figure 4.2 match the users' perspectives when asked to rate the difficulty level for reproducing the sample notes (see Figure 4.3). On a 5-points Likert scale where 1 means "Very Easy" and 5 means "Very Difficult", the participants assessed the difficulty encountered when trying to reproduce the samples. They were requested to rate the difficulty in reproducing the samples' pitch, timbre, and amplitude, as well as the perceived difficulty in additively comparing these sound characteristics. From the results, we observe that the participants perceived a higher difficulty in using the tool to reproduce the sound features than actually additively comparing the three

Figure 4.3: The graph brings the users' perspective regarding the difficulty level of reproducing and additively comparing the samples concerning individual sound characteristics (amplitude, pitch, and timbre). we used a 5-points Likert scale where 1 means "Very Easy" and 5 means "Very Difficult".

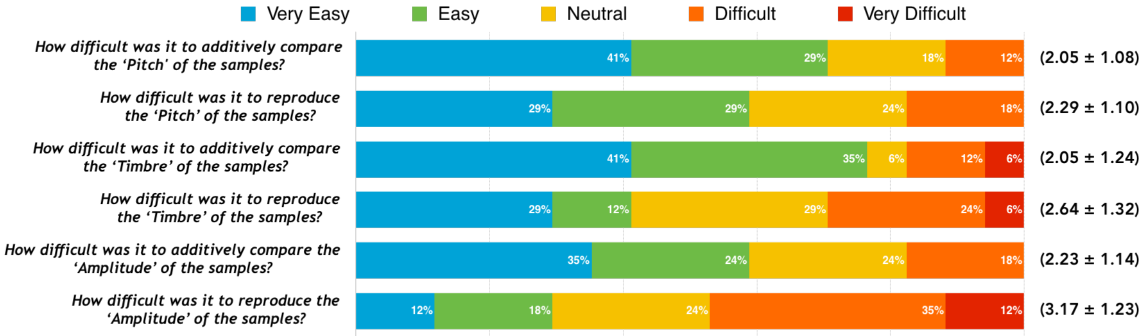
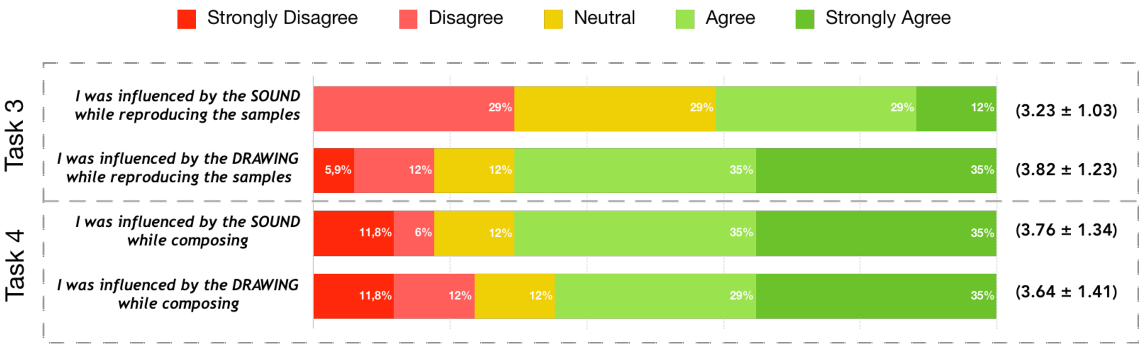


Figure 4.4: The figure presents the impact that both drawing and sound outputs had on participants during tasks T3 and T4 on a 5-points Likert scale where 1 means "Strongly Disagree" and 5 means "Strongly Agree". The results show that while performing task T3, the subjects were slightly more impacted by the visual strokes than by the sound.

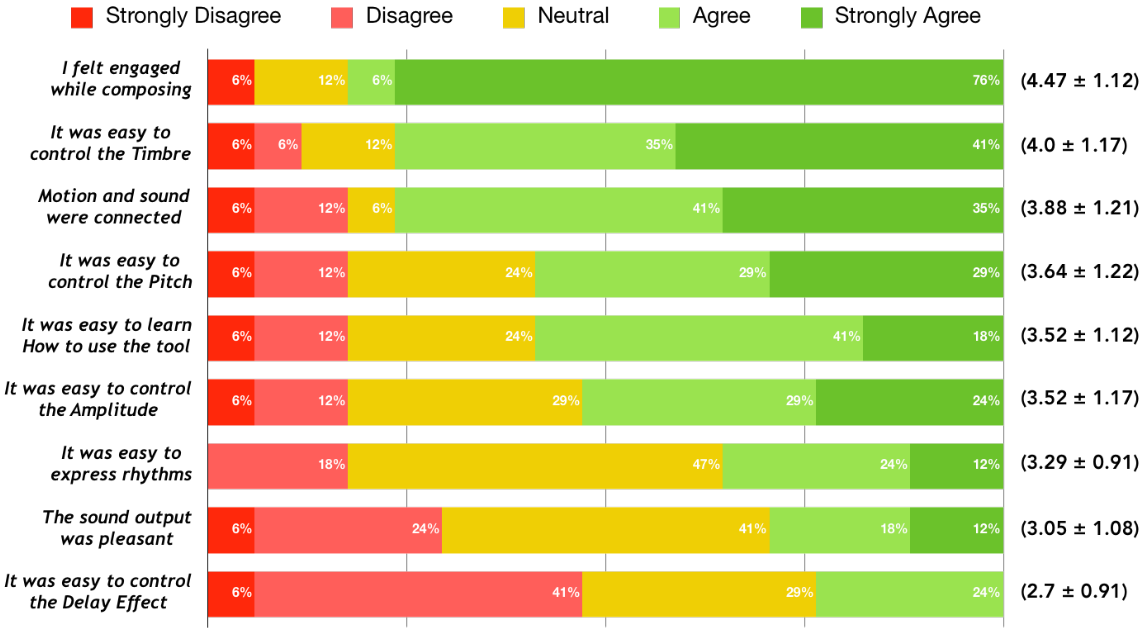


sound aspects (timbre, pitch, and amplitude). Regarding the reproduction aspect, 47% of the participants answered that reproducing the amplitude of the samples was "Difficult" or "Very Difficult". Reproducing the timbre and pitch of the samples was considered "Difficult" or "Very Difficult" by, respectively, 30% and 18% of the participants.

We were also particularly interested in investigating how the audiovisual outputs influenced users while making use of *Musical Brush*. To explore this topic further, we requested the participants to inform the level of impact that both sound and drawing output feedback had on the accomplishment of tasks T3 and T4. Through the use of a 5-point Likert scale where 1 represents "Strongly Disagree" and 5 "Strongly Agree", users tended to report that both sound drawings were equally impacting in T4. In T3, which involved the reproduction of sample performances, participants managed to be slightly more influenced by the visual outputs, (See Figure 4.4).

Figure 4.5 brings the results obtained from Q5, where the participants replied to

Figure 4.5: The figure brings Q5 results regarding the overall experience of the app usage on a 5-points Likert scale where 1 means “Strongly Disagree” and 5 means “Strongly Agree”.



overall questions regarding different aspects of the application usage. In these questions, we used a 5-points Likert scale where 1 represents “Strongly Disagree” and 5 “Strongly Agree”. The average and standard deviation values are shown at the far right of the image for each investigated topic.

In general, issues related to misinterpreted interactions were mainly occasioned by two reasons: (i) the mapping between motion and sound, and (ii) the activation of the delay effect. The first was essentially related to the fact that in this first version of the app, the virtual strokes were always originated from the center of the device screen, not following finger motion swipe gestures. Among the comments, we highlight: *“I was a bit unsure if where I was located was going to influence the instrument, or just what kind of movement I did with the phone”*, (P7); *“The brush did not align with my finger when drawing which made the duplication test a bit awkward”*, (P8); and *“I did not know if I should move my finger, my arm (or whole-body), or the phone itself”*, (P11). In relation to the delay effect, we noticed that participants had problems with controlling or forgetting the existence of the feature: *“Controlling delay was a bit difficult, I didn’t seem to get it half the time”*, (P8); *“It’s easy to forget that the delay effect is there, and thrusting the phone affects the other components, so it is a bit difficult to use”*, (P9); and *“I forgot about the delay effect, so I didn’t use it, but I remember it was a bit more difficult to understand (the controls)”*, (P11).

Some interesting observations were made regarding how the virtual drawings output impacted users while creating the performances: *"It made me less conscious about the sounds, and "freer" when musicking."*, (P6); *"It was cool to see a visualization of the music!"*, (P7); *"My focus was on the drawing first, then listening to what sounds this drawing created later."*, (P8); *"It was cool to see the drawing in AR. The tracking of the drawings in space is impressive to me."*, (P9); and *"I mostly tried to go for visually pleasing performances, sometimes I'd almost forget how they would sound"*, (P12). Besides that, some of the participants mentioned how the presence of the strokes was responsible for influencing them to move while performing: *"There was no real reason to move around since only the vertical movement of the phone changed the sound, but still, I was motivated by the created strokes"*, (P1); and *"It helped me to move my full body, and I like it!! Something to look at, but something I also can forget. It is like a graphic score or the trace of my body musical expression."*, (P11);. On the other hand, the need to move the device for interacting with the application was seen as an issue for two users: *"Too much arm movement, my arm, and hand are tired"*, (P11); and *"I felt a bit dizzy because the movements had to be large in order to create my composition with my desired pitch."*, (P13).

Concerning sound, the general opinion is that improvements could be made in an attempt to make the audio output more complex, or including a more significant number of different timbres: *"[...] also think that adding extra features that are harder to use could be fun for the user so it's like you have to learn to use the app just like any other instrument"*, (P2); *"An interesting feature would be to have some more rhythmic sounds, like drums, etc."*, (P4); *"[...] also it would be awesome to have some more complex sounds in addition to the simple waveforms (drums, noise, bowed instruments, etc.)"*, (P8); P14 mentions that the current sound is pleasurable since it resembles electronic music, but also says that *"could experiment to mix some other sounds, like violin or saxophone"*; and *"The timbres should sound better"*, (P16).

On the other hand, despite the current simple timbres, people were generally very engaged in the use of the app, as shown in Figure 4.5. The possibility of visualizing and walking within the performance in the real environment was highlighted by several participants, also mentioning the fun provided by using the application, especially in the free improvisation task T4: *"I think it is an overall fun application to use"*, (P2); *'I enjoyed the app, but I really disliked having to recreate compositions"*, (P13); *"I would love to see this with dancers doing a coreography"*, (P15); and *"The compositional part* *was very fun!"*, (P17). Besides this, some suggestions for further development were raised such as extending the tempo and the maximum quantity of tracks for the performances: *"I fell like I would like to have a bit longer record time"*, (P7), and *"It would be great to have longer recording time and more layers"*, (P8); or being able to manipulate the distance from which the lines are drawn: *"it would be nice if we could adjust the depth where we are drawing our music"*, (P10).

In general, participants presented no great difficulties for controlling and expressing rythms. The most common mistake was during the track recording process, where some subjects did not perceive that the 8 seconds track time was about to finish, and may have negatively affected some of the performances.

Characteristic	**User feedback**
Gesture Mapping	*"It is not completely intuitive that elevation and not only angle changes pitch" (P6)*
	"I was a bit unsure if where I was located was going to influence the instrument, or just what kind of movement I did with the phone" (P7)
	"The brush did not align with my finger when drawing which made the duplication test a bit awkward" (P8)
	"I did not know if I should move my finger, my arm (or whole-body), or the phone itself" (P11)
Delay Effect	*"Controlling delay was a bit difficult, I didn't seem to get it half the time"* (P8)
	"It's easy to forget that the delay effect is there, and thrusting the phone affects the other components, so it is a bit difficult to use" (P9)
	"I forgot about the delay effect, so I didn't use it, but I remember it was a bit more difficult to understand (the controls)" (P11)
Physical Tiredness	*"Too much arm movement, my arm, and hand are tired"* (P11)
	"I felt a bit dizzy because the movements had to be large in order to create my composition with my desired pitch." (P13)

Visual Impact	*"There was no real reason to move around since only the vertical movement of the phone changed the sound, but still, I was motivated by the created strokes"* (P1)
	"It made me less conscious about the sounds, and "freer" when musicking." (P6)
	"My focus was on the drawing first, then listening to what sounds this drawing created later" (P8)
	"It was cool to see the drawing in AR. The tracking of the drawings in space is impressive to me." (P9)
	"It helped me to move my full body, and I like it!! Something to look at, but something I also can forget. It is like a graphic score or the trace of my body musical expression." (P11)
	"I mostly tried to go for visually pleasing performances, sometimes I'd almost forget how they would sound" (P12)
Sound	*"[...] also think that adding extra features that are harder to use could be fun for the user so its like you have to learn to use the app just like any other instrument"* (P2)
	"An interesting feature would be to have some more rhythmic sounds, like drums, etc." (P4)
	"[...] also it would be awesome to have some more complex sounds in addition to the simple waveforms (drums, noise, bowed instruments, etc.)" (P8)
	"The sound is very electronic, and it's cool, but, could experiment with other sounds, like violin or saxophone, to mix more the sounds" (P14)
	"The timbres should sound better" (P16)

General	*"I think it is an overall fun application to use"* (P2)
	"I enjoyed the app, but I really disliked having to recreate compositions" (P13)
	"I would love to see this with dancers doing a coreography" (P15)
	"The compositional part was very fun!" (P17)
	"I fell like I would like to have a bit longer record time" (P7)
	"It would be great to have longer recording time and more layers" (P8)
	"it would be nice if we could adjust the depth where we are drawing our music" (P10)

Table 4.1: Participants comments and observations regarding *Musical Brush* main features and characteristics during the user study.

4.3 Discussion

The results obtained from the user evaluation show that the most significant number of participants has some degree of auditory training, being able to correctly distinguish different sounds (amplitude, pitch, and timbre) during task T1 in 94% of the cases. This finding points out that any difficulties in replicating the sounds are unlikely to be caused by users' ear perception but from other aspects of the interface.

In this sense, some of the proposed interactions were not as intuitive as expected. An example is the low rate of correct amplitude reproduction during T2 (16,47%), which could be possibly caused by the higher degree of sensitivity of its control if compared to other sound parameters. The pitch variation, for example, consists of a smoother transition along the entire vertical axis. Therefore, controlling the amplitude through pressure touch, also due to its reduced range of variation, seemed harder to be accurately mastered. It is also true that pitch variation is more sensitive to be perceived if compared to amplitude variations. Furthermore, although strong touches produce sound with larger amplitude, the non-deforming device screen does not provide any feedback regarding the isometric force of the touch interactions. Another reason for this low rate of correct reproductions is the soft amplitude variation from one sample to another if compared to the easily notable pitch changes. As a result, several participants reported the non-perceived alterations in amplitude, therefore not reproducing such changes. Concerning the delay effect, despite its sound effect being liked by several of the subjects, many of them reported forgetting the feature or not being able to activate it properly. Moreover, the need to swing the device to activate the function does not seem the right choice since this will modify the pitch value and possibly lead to a loss in the geospatial reference of the virtual objects.

Concerning the virtual drawings, the behavior where the strokes are created initially from the middle of the screen and not following the finger slide movement caused some confusion. In this case, some participants had initial issues on the understanding that the entire device should be moved in order to manipulate the position of the strokes. A positive point from the users' perspective was the influence of the three-dimensional drawings during the execution, being described as appealing and motivational. This aspect could also be related to the high level of engagement reported by the user feedback (see Figure 4.5). Besides, the importance given by the subjects to the visual output while performing, being considered as crucial as the sound in T4 (see Figure 4.4) or even more impacting (see Table 4.1), was unexpected.

In general, even though the tool uses straightforward timbres and does not contain resources for creating complex musical pieces, the participants described the application as very engaging and enjoyable. The user feedback collected during the experiment regarding the creative impact that the tool had on individuals guided us to perform a second analysis focused on exploring the effectiveness of *Musical Brush* concerning the support of creative characteristics.

4.4 Prototype Modifications

From the results obtained in our user study, we made structural changes in our application (see Table 4.2). Among the key points observed, *Musical Brush* prototype featured some interactions of difficult comprehension or control. Among the key issues, we highlight the problems in controlling the delay effect, the excessive sensibility when using pressure touch events to control amplitude, and not using the position of the finger on the screen during touch events to create virtual strokes according to the movement of the touch. To fix these issues, several modifications have been implemented.

The most notable difference present in the second version of the application is that now the tool tracks the finger position on the screen to create a stroke based on that location. This means that not only the device motion but the finger swipe gestures control the drawing directions. We noticed that this new interaction facilitates the understanding of the feature and also helps to improve the accuracy and control of the drawings. Besides,

Table 4.2: A summary of the modifications applied to *Musical Brush* after collecting feedback in our first exploratory user study.

Modified Feature	Previous	Current
Delay Effect Activation	Device abrupt swing	Movement speed of device above a given limit
Drawing Control	Device movement	Device movement and swipe gestures
Amplitude Control	Amplitude range: [0.1 - 0.5]	Amplitude range: [0.0 - 0.6]

this new gesture seemed to be more natural to users as it mimics the concept of drawing with a brush on a canvas.

The delay effect activation trigger was also modified. In the first version, it was necessary to swing the device abruptly to turn the effect on. However, in several of the attempts users encountered difficulties caused by some failure in recognizing the interaction or losing the camera's reference points that maintained the AR virtual elements positions. The solution found was to use the accelerometer to control this functionality, thus activating the effect when the device's movement speed exceeded a fixed limit of 1.25 m/s. Lastly, the amplitude control sensibility was also modified to provide a smoother and noticeable transition for users. The oscillators minimum and maximum amplitude values were respectively decreased (from 0.1 to 0.0) and increased (from 0.5 to 0.6), thus widening the gap between the boundaries and facilitating the perception of alteration and control.

4.5 Summary

Aiming the evaluation of the proposed *Musical Brush* prototype, we conducted an exploratory study where it was possible to make observations and collect user feedback. We observed that some interactions were not as intuitive as expected. Examples include forgetting the existence of the delay effect, the misunderstanding caused by not tracking finger gestures when creating the virtual strokes, and the too sensitive amplitude pressure control. On the other hand, the engagement and enjoyability levels, mostly caused by the tool's visual appealing were positively highlighted by the participants. With this in mind, we decided to conduct a second user study focused on understanding how the proposed tool (*Musical Brush*) could support creativity. The details of this second study are presented in the following chapter.

5 USER STUDY II - CREATIVITY SUPPORT EVALUATION

This chapter presents the details regarding our second user study of *Musical Brush*. This experiment focused on exploring the effectiveness of our prototype concerning the support of creativity characteristics. More specifically, we are interested in the investigation of three main topics: (1) *Is the design of Musical Brush successful in supporting creativity?*; (2) *What aspects of creativity are impacted most?*; and (3) *What are the key features that impact substantially on this support?*

Along with the subjective opinion form participants, the data used on further analysis related to the application usage is captured during the experiments. Musical Brush records the interactions of each user session, enabling us to gather statistics regarding how the tool is being used on each different configuration. We start by discussing the challenges and methods of measuring and evaluating both creativity and Creativity Support Tools in Section 5.1. Section 5.2 details how we designed the experiment. Finally, in Sections 5.3 and 5.4 we detail and discuss the results, respectively.

This study was held at the Federal University of Rio Grande do Sul (UFRGS), in Porto Alegre - Brazil, at the Department of Informatics.

5.1 Creativity Evaluation

Although intuitively comprehended by most people, the concept of creativity is not easy to define. Early works in the field explored the topic back in the 1930s and 1940s, associating creativity with cognitive psychology. Classic definitions refer to 'creativity' as the ability to produce work that is both novel and useful (OCHSE; OCHSE; OCHSE, 1990; LUBART, 1994). Despite the long years of research, more recent works still foresee a great challenge for the upcoming years in an attempt to develop a clearer definition of creativity, turning it into a more concrete topic (STERNBERG, 1999).

Hocevar (1981) divided the approaches for measuring creativity into ten categories: test of divergent thinking, attitude and interest inventories, personality inventories, biographical inventories, teacher nominations, peer nominations, supervisor ratings, judgments of products, eminence, and self-reported creative activities and achievements. Although each of them offers its qualities and deficiencies, the divergent thinking tests have been the most widely used for decades. These tests, which are based on Guilford (1956)'s structure of the intellect model, commonly distinguish from traditional intelligence tests

Figure 5.1: The figure details the equation for scoring the CSI. The score is obtained by summing the agreement rating statements for each factor. After that, each factor subtotal is multiplied by its factor comparison count (i.e., the number of times the factor was chosen during the paired-factor comparison. Lastly, the sum is divided by three, resulting in a value ranging from 0 to 100.

$$
\begin{aligned}
\text{CSI} = \Big[& (\text{Collaboration1} + \text{Collaboration2}) * \text{CollaborationCount} \; + \\
& (\text{Enjoyment1} + \text{Enjoyment2}) * \text{EnjoymentCount} \; + \\
& (\text{Exploration1} + \text{Exploration2}) * \text{ExplorationCount} \; + \\
& (\text{Expressiveness1} + \text{Expressiveness2}) * \text{ExpressivenessCount} \; + \\
& (\text{Immersion1} + \text{Immersion2}) * \text{ImmersionCount} \; + \\
& (\text{ResultsWorthEffort1} + \text{ResultsWorthEffort2}) * \text{ResultsWorthEffortCount} \Big] \; / \; 3.0
\end{aligned}
$$

Source: (CHERRY; LATULIPE, 2014)

by demanding not a single response but multiple elaborated answers, focusing, in general, on evaluating intellectual abilities such as fluency, flexibility, originality, redefinition, elaboration, etc. Several are the existent divergent thinking tests, the Alternative Uses Test (CHRISTENSEN et al., 1960), for instance, requests for participants to state as many uses as possible for a simple object, evaluating how people can generate a wide range of answers and solutions to a single problem. The user study described in this current chapter used the divergent thinking test and asked for participants to list uses for a 'brick'.

If defining and evaluating creativity is not a trivial task, the ability to measure if a tool promotes creativity on individuals is also challenging. According to Shneiderman and Ben (2007), one of the main difficulties in evaluating CSTs is the lack of obvious metrics to quantify its success. Constantly being approached in distinct ways by the community (CARROLL; LATULIPE, 2012), the evaluation of CSTs is commonly explored through qualitative methods such as in-depth interviews or observations. Despite extremely productive, these methodologies do not provide an easy comparison between tools and analysis of statistically significant differences. In an attempt to overcome the lack of a specific set of converging metrics when evaluating CSTs, the Creativity Support Index (CSI) (CHERRY et al., 2009; CHERRY; LATULIPE, 2014) measurement tool was proposed. The protocol brings a psychometric survey designed specially to measure the capacity of CSTs on supporting individuals engaged in creative work.

Through a series of objective questions similar to the NASA Task Load Index, the CSI consists of a rating scale section and a paired-factor comparison section, and measures how well a tool assists a user engaged on creative work by measuring the following six factors:

- *Results Worth Effort*, related to the degree of user satisfaction when using the tool;
- *Exploration*, measured by how easy it is to explore different possibilities through the tool;
- *Collaboration*, defined by how easy it is to share ideas and collaborate using the tool;
- *Immersion*, indicating how absorbed users are in the activity while using the tool;
- *Expressiveness*, measured by how the tool enables users to be creative;
- *Enjoyment*, which relates to how much users like to use the tool.

For each of the above factors, participants have to rate two statements on a scale from "Highly Disagree" (0) to "Highly Agree" (10) concerning the degree of support regarding the respective creative characteristics. The output from the CSI test is calculated following the equation in Figure 5.1, represented as a score out of 100 where higher scores represent better creativity support.

5.2 Experiment Design

5.2.1 Compared Versions

In our user study, we compare four different versions of *Musical Brush* (*AR, Sound Only (SO), 3D,* and *2D*) with the ambition to measure how the different types of interactions and visualizations affect creativity. The three first modes (*AR, SO,* and *3D*) present the same interaction rule, where both the touch gestures and device motion are used to draw, and consequently, to compose music. The difference lays in the visual elements. The *AR* version presents the user with the camera real image, positioning the virtual strokes on top of the three-dimensional environment scene. The *3D* version, on the other hand, immerses the user in a “virtual” environment, where an infinite checkered floor replaces the camera image mentioned previously. Finally, the *SO*, as the name suggests, does not present any virtual stroke to the user, being sound the only output from the tool in this version. Unlike the above-mentioned versions (AR, SO, and 3D), in the *2D* version, the motion of the device does not impact the output, being the audiovisual output exclusively affected by the touch gestures on the device screen. Table 5.1 and Figure 5.2 summarize

Table 5.1: A summary of the characteristics of each application version. Real Env. (Real Environment), Virtual Env. (Virtual Environment) and Black Img. (Black Image)

Version	AR	SO	3D	2D
Visual Feedback	Yes	No	Yes	Yes
Interactions	3D	3D	3D	2D
Screen Background	Real env.	Real env.	Virtual env.	Black img.

and illustrate the characteristics present in each of the compared versions.

5.2.2 Hypotheses

The following specific hypotheses were defined for the user study:

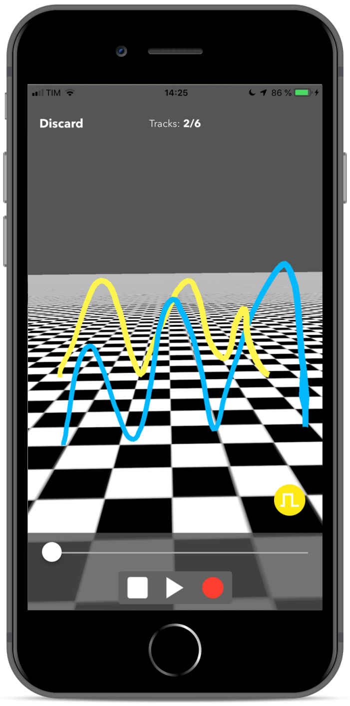
- ***H1* - *Users will experience higher levels of creativity when presented to visual feedback rather than only sound in the AR condition.***
  We believe that the additional visual feedback will improve the level of support for creativity provided by the tool since users will be able to view the 'shape' of the musical piece they are designing. The drawings will also embed the temporal memory of the piece, helping the perception of the piece as a whole.

- ***H2* - The three-dimension interactions will cause users to experience higher levels of creativity than the 2D condition.**
  We suppose that the extra dimension will positively impact the level of support for creativity perceived by the participants since it provides greater freedom for movements and more design alternatives. Besides, the additional dimension expands the limited design canvas present in a standard 2D approach.

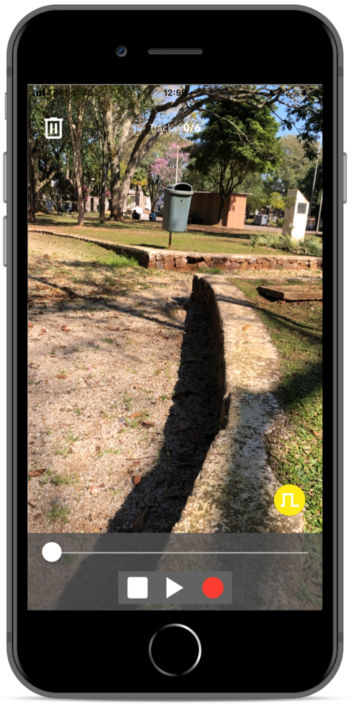
- ***H3* - The 2D condition will be perceived as more comfortable and easy to use than the 3D interaction conditions.**
  We believe that the 3D condition will be perceived as more physically demanding than the standard 2D. We hypothesize that once the 3D drawings are mainly controlled by the movement of the device and require the participants to move the smartphone instead of just drawing on the screen, the unconventional design may

Figure 5.2: Screenshots from each of the four distinct compared versions of Musical Brush. Subfigures 5.2a, 5.2b, 5.2c, and 5.2d bring respectively examples of performances in the 2D, 3D, SO, and AR versions.

(a) 2D



(b) 3D



(c) Sound Only (SO)

(d) Augmented Reality (AR)

turn the handle of the tool more challenging.

Furthermore, we sought to conduct an exploratory study regarding the impact that the real environment has over users during creative work. Therefore, a comparison of the 3D condition with and without AR was performed to explore how the environment can affect the support of creativity for users. Our motivation was to understand if and how users would explore features or objects present in the environment to aggregate in their improvisations.

5.2.3 Protocol

The experiment consisted of a user study conducted with a total of 26 subjects. No previous knowledge or experience in any specific area was required for the study. Also, since the experiment required subjects to move while using the application, we restricted the participation of users that did not present any mobility issues. The experiment was designed as a within-subjects study where each user experienced all the four different application versions. To prevent results from being biased, the sequence of versions to be tested was different in each user session. Furthermore, the device chosen for the experiments was a 5.5 inch-display iPhone 8 Plus smartphone running iOS 12.1.2. Each experiment lasted for approximately 45 minutes, and was subdivided into the four following stages: ***Introduction*** $\rightarrow$ ***Learning*** $\rightarrow$ ***Performing*** $\rightarrow$ ***Feedback.***

The *Introduction* stage began by explaining the objective of the study and its composition. Then, after accepting the terms and conditions of the study, Q1 was applied. After that, the Guilford's Alternative Uses Task test was applied (GUILFORD, 1967). In this test, volunteers were asked to list as many uses as possible for a common household object (a "brick", in this case) in 1 minute and 30 seconds, the resulting test score is a sum of points based on four components and represents how participants were able to think creatively. The aspects evaluated are:

- *Originality* - Indicates how unique was each response compared to the total amount of responses from all participants. Responses that were given by only 5% of the test group are considered unusual (1 point), while responses that were given by only 1% of the group are considered unique (2 points);
- *Fluency* - The ammount of alternative uses given by the participants (*N* responses

= *N* points);

- *Flexibility* - Represented by the range of ideas, in different categories (*N* categories = *N* points);
- *Elaboration* - Evaluates the amount of details of each alternative use (*No detail* = 0 points; *Brief details* = 1 point; *Further explanations* = 2 points).

The *Learning* stage was composed of a brief explanation of the features and general operation of the tool. In this stage, the four different application versions detailed on Subsection 5.2.1 were presented to the participant. Meanwhile, volunteers were encouraged to explore the tool and ask questions.

The *Performing* stage was the central part of the experiment. In this phase, participants were asked to create one performance for each of the different versions. The content of the performances was free, and no time limits or any other restrictions were applied. After finishing each performance, participants were asked to answer Q2. Lastly, after completing all the four performances, Q3 was applied. During the test, volunteers used a headphone (WH-CH700N Sony) to prevent outside noise from disrupting the experiment. Figure 5.3 illustrates this scenario.

Lastly, users were free to express their thoughts about the full experience while answering Q4. The participants were rewarded with chocolate in recognition of their help.

5.2.4 Questionnaires

The questionnaires applied in this study are summarized here.

The *Intake Questionnaire* (Q1) (see Appendix D) collects the participants' demographic information, as well as previous experience and knowledge regarding technology and music issues.

The *CSI Questionnaire* (Q2) (see Appendix E), presented after each version session, asks specific questions regarding the impact of the tool on creativity. The questions explore different creative characteristics, which are: exploration, immersion, results worth effort,

Figure 5.3: The image shows one of the study participants performing tasks while using the AR version.

expression, collaboration, and enjoyment. Since our application does not provide collaboration, we removed this option from this questionnaire.

The *CSI Pos-Questionnaire* (Q3) (see Appendix F) presents a paired-factor comparison among the creative characteristics explored in Q2. The idea is to identify what were the attributes prioritized during the task accomplishment.

The *Feedback Questionnaire* (Q4) (see Appendix G) consists mostly of subjective questions. With this, we aimed to explore the participants' points of view on how the different interaction and visualization versions of the application affected the creative process.

5.2.5 Usage Logs

Through data gathered from the experiments, we have access to all participants' improvisations. From these samples, we were able to extract data regarding user interactions and performance characteristics that will be used in further analysis and possible identification of usage patterns. The following list describes the tracked attributes and their definitions:

- *Duration (s):* Amount of time (in seconds) used to complete the task;
- *Used Tracks:* The number of different tracks (maximum of 6) used to create a performance;
- *Discarded Tracks:* After creating a track, users could discard it if the result was not satisfactory. This property refers to the total number of discarded tracks while creating a performance;
- *Used Timbres:* The number of different timbres (maximum of 4) used to create the performance;
- *Distance (m):* The total movement distance (in meters). This is related to the movements used in 3D interaction modes;
- *Horizontal Distance (m):* The total horizontal movement distance (in meters). This value is associated with 3D interaction modes only;
- *Vertical Distance (m):* The total vertical movement distance (in meters). This value is associated with 3D interaction modes only.

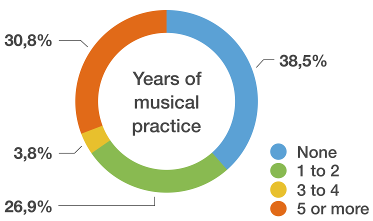
5.2.6 Population

The data from Q1 provides us with the necessary demographic information from the participants of the experiment. Among the 26 subjects, 23 were male and 3 female, with age ranging from 18 to 28 (22.61 ± 2.60). Most of the subjects had at least some previous experience in musical practice (only 38.5% never practiced any instrument before). Regarding technology, most of them never had any previous experience with mobile apps whose purpose was music creation (69.2%), and only 19.2% of the participants had used more than one app that explored AR technology on mobile devices (see Figure 5.4).

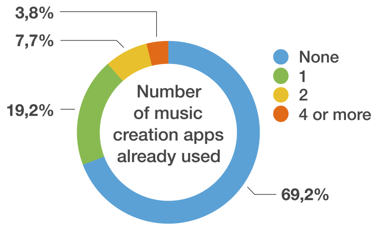
5.3 Results

The data from all the four questionnaires were analyzed by calculating the average (μ) and standard deviations (σ) for each question, and are reported here as $\mu \pm \sigma$. The Shapiro-Wilks Test (SHAPIRO; WILK, 1965) was applied for normality investigation. The results indicate that our samples deviate from a normal distribution. Therefore, we used the non-parametric Kruskal-Wallis Test (KRUSKAL; WALLIS, 1952) to identify significant differences between the four groups. Finally, a Dunn's Multiple Comparison post hoc test

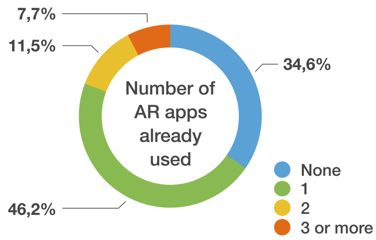
Figure 5.4: The graphs present demographic information from participants. Figure (a) brings information regarding previous experience in music practice. Figure (b) and (c) detail, respectively, the participants' experience with applications that explore music creation and Augmented Reality.



(a)



(b)



(c)

Figure 5.5: Histogram presenting the results for the Divergent Thinking Test. The horizontal axis represents the test score ranges, while the vertical axis represents the number of participants with the score within that range.

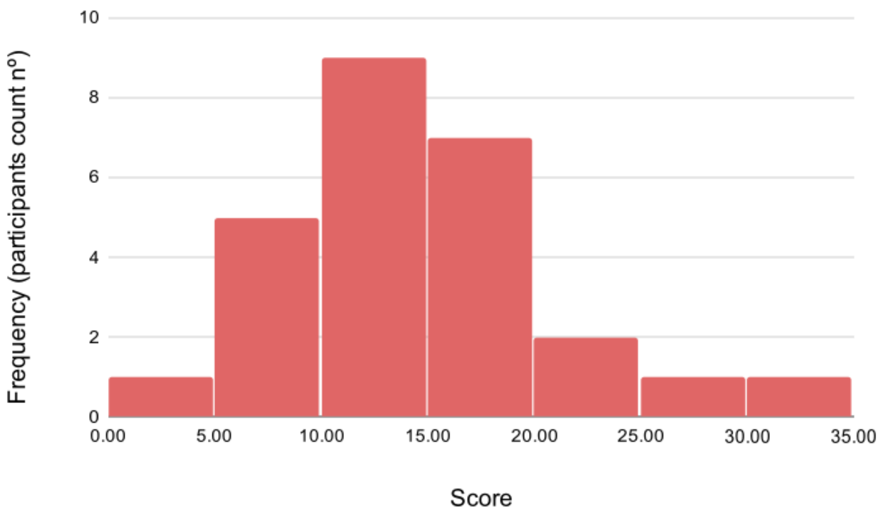


Table 5.2: Final CSI Score and individual creativity attribute scores for each of the four compared versions. Bold values indicate the highest average value.

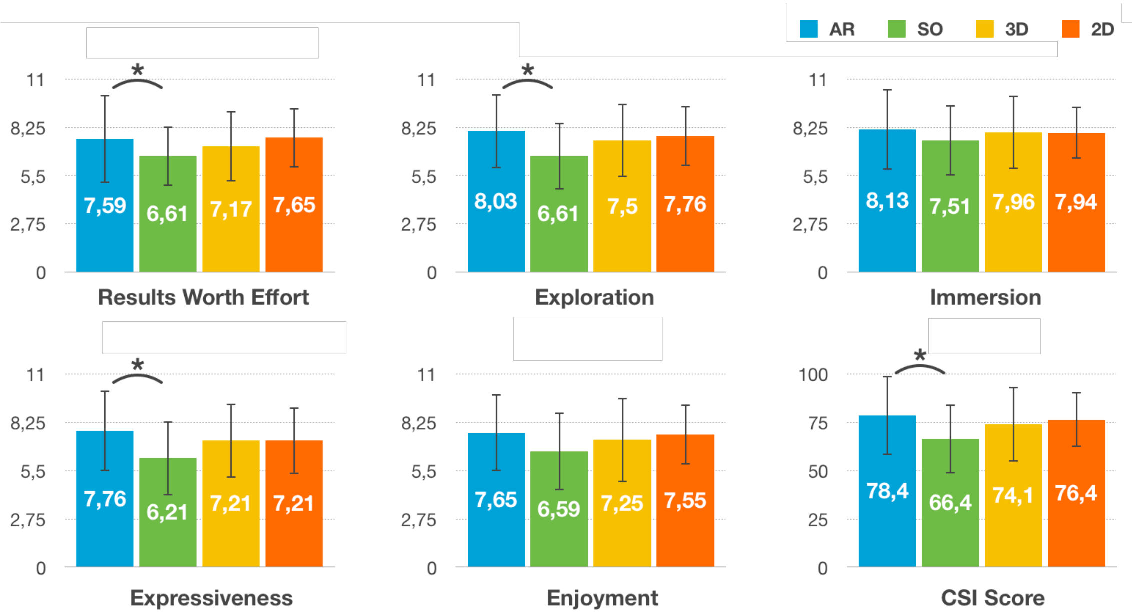
Attribute	AR	SO	3D	2D
Results Worth Effort	7.59 ± 2.5	6.61 ± 1.7	7.17 ± 2.0	**7.65** ± 1.7
Exploration	**8.03** ± 2.1	6.61 ± 1.9	7.5 ± 2.1	7.76 ± 1.7
Immersion	**8.13** ± 2.3	7.51 ± 2.0	7.96 ± 2.1	7.94 ± 1.5
Expressiveness	**7.76** ± 2.3	6.21 ± 2.1	7.21 ± 2.1	7.21 ± 1.9
Enjoyment	**7.65** ± 2.2	6.59 ± 2.2	7.25 ± 2.4	7.55 ± 1.7
CSI Score	**78.4** ± 20.6	66.4 ± 17.8	74.1 ± 19.3	76.4 ± 14.1

(DUNN, 1964) was applied when necessary for the dependent variables with different distributions. To test the correlation between the variables we used the Spearman rank-order correlation coefficient (SPEARMAN, 1904). Significance level regarding the statistical tests is indicated in the figures as follows: (*) for $p < 0.05$, (**) for $p < 0.01$, and (***) for $p < 0.001$.

5.3.1 Resulting Data

Figure 5.5 brings the resulting histogram of the divergent creative thinking test (Guilford's Alternative Uses) applied to participants. Individual scores range from 4 to 31, with the highest score occurrences in the range from 10 to 15 (9 participants), the overall result score average and standard deviation were (14 ± 6.11). Table 5.2 and Figure 5.6 bring the results obtained from Q2. The values of the first five creativity-related attributes (*Results Worth Effort, Exploration, Immersion, Expressiveness*, and *Enjoyment*) range from 1 to 10 and are the basis for calculating the CSI score, whose maximum value is 100. As we can notice, the AR version was superior in the final CSI score, as well as for all the other creativity attributes except for *Results Worth Effort*. Two very high scores include the perception of *Immersion* and the *Exploration* capability with the AR version. Among the results, *Results Worth Effort*, *Exploration*, *Expressiveness*, and the *CSI Score* were significantly different (with p = 0.03, 0.01, 0.02, and 0.01, respectively) among *AR* and *SO* versions. Figure 5.7 brings which were the most important creative-related characteristics for participants during the task. We see that the most prioritized attributes were *Exploration* (28%) and Expressiveness (23%). The CSI results match the feedback given by users on Q4, where when asked about their preferences, 57.7% of the

Figure 5.6: Results from Q2 for each attribute measured by the CSI and its final score. The results were provided through user feedback and represent the average of two distinct questions, with a score ranging from 1 to 10 concerning the creativity support for each of the analyzed attributes. Significant differences were observed regarding *Results Worth Effort*, *Exploration*, *Expressiveness*, and the *CSI Score* between AR and SO conditions.



participants elected the *AR* as the most preferred version, against only 3.8% for the *SO* mode. The *SO* was also pointed as the least favorite version by 65.4% of the volunteers, with most justifications reporting the lack of visual elements.

The Table 5.3 summarizes data from the user improvisations. The data presented here is described in Subsection 5.2.5 and its analysis can reinforce some of our insights from the results related to the measurement of creativity support. Figure 5.8 brings together the CSI and performance-related attributes in a correlation matrix. As we can see, characteristics such as the number of tracks and timbres used in a piece are positively related to the perceived level of creativity-related attributes by users, while enjoyment is connected to the creative thinking capacity level of subjects. As expected, all the CSI measured attributes (Results Worth Effort, Exploration, Enjoyment, Expressiveness, Immersion) presented very high scores regarding positive relation to each other. The same happens for the distance values collected during the experiments (Distance, Vertical Distance, Horizontal Distance).

Table 5.3: Summary of usage logs for each of the four compared versions. Bold values indicate the highest average value, while '-' denotes that the variable was not measured for such condition. The *AR* version presented the highest average for duration time and number of created/discarded tracks. The *3D*, on the other hand, was the one with the highest levels of device displacement while performing. No significant differences were found for the different modes.

Characteristic	AR	SO	3D	2D
Duration (s)	**184** $\pm$ 88.4	128 $\pm$ 43.7	160 $\pm$ 72.6	139 $\pm$ 64.3
Used Tracks	**4.11** $\pm$ 1.1	3.8 $\pm$ 1.1	4.0 $\pm$ 1.1	3.92 $\pm$ 0.6
Discarded Tracks	**1.15** $\pm$ 2.0	0.80 $\pm$ 1.2	0.5 $\pm$ 0.9	0.84 $\pm$ 1.4
Used Timbres	3.30 $\pm$ 0.8	3.03 $\pm$ 0.7	**3.46** $\pm$ 0.8	3.30 $\pm$ 0.7
Horizontal Distance (m)	5.34 $\pm$ 3.6	4.35 $\pm$ 3.5	**6.23** $\pm$ 4.8	–
Vertical Distance (m)	4.31 $\pm$ 3.3	3.99 $\pm$ 2.6	**4.32** $\pm$ 3.4	–
Distance (m)	7.72 $\pm$ 5.1	6.60 $\pm$ 4.5	**8.57** $\pm$ 6.0	–

Figure 5.7: Graph brings the results of Q3, where users had to inform in a pairwise comparison among all the 5 creativity-related attributes, which he/she prioritized during the experiments. Results show that Exploration (28%) and Expressiveness (23%) were the most essential creative-related characteristics for users during the composition task.

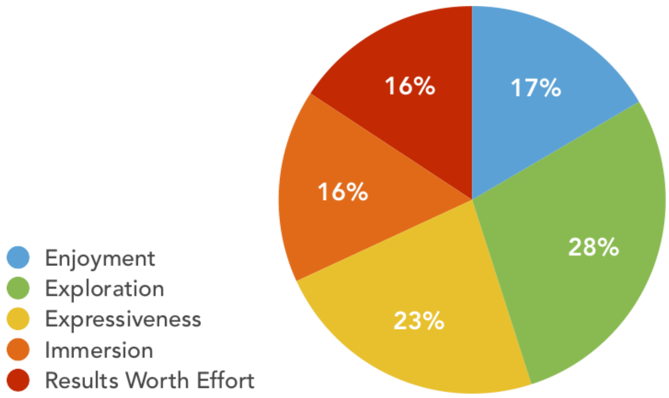
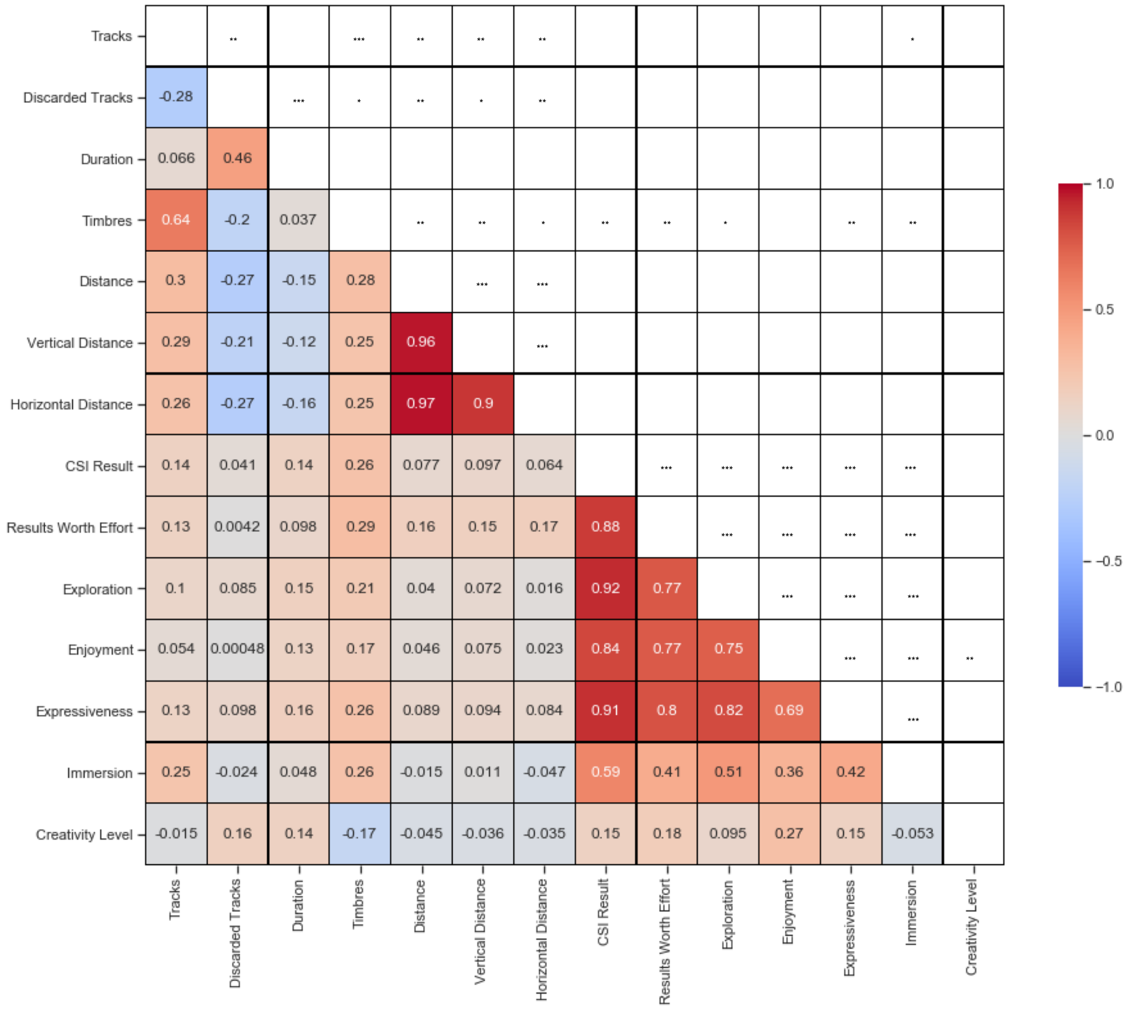


Figure 5.8: Correlation matrix presenting the correlation coefficients when comparing the different measured variables. The color of each cell represents the value of the correlation, ranging from red (positive correlation) to blue (negative correlation).



5.4 Discussion

We start by discussing the overall results collected during the study, exploring the three questions raised at the start of this chapter:

1. *Is the design of Musical Brush successful in supporting creativity?*
2. *What aspects of creativity are impacted most?*
3. *What are the key features that impact substantially on this support?*

In general, *Musical Brush* presented high scores for all the individual creativity-related attributes measured by the CSI (see Table 5.2). As the final output score, in a range from 0 to 100, the tool scored 78.4. The highest scores for individual attributes were ‘Immersion’ and ‘Exploration’, given a range from 0 to 10, presented scores of 8.13

and 8.03, respectively. At the final pair-wise comparison among the measured attributes, ‘Exploration’ was considered more important than any other characteristic, with 28% of the answers relating this as the most essential characteristic of the tool.

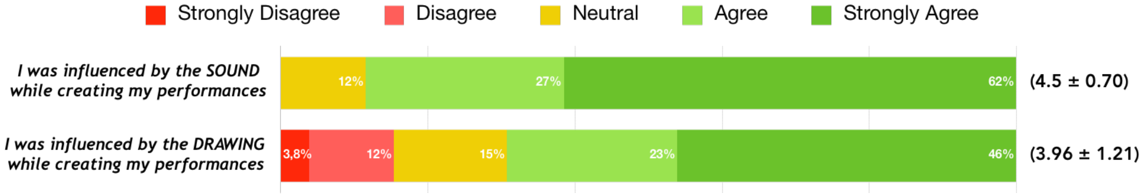
The correlation matrix present in Figure 5.8 provides us with more advanced analysis. When observing the ‘CSI Result’ correlation indexes, we see that among all the five CSI measured attributes, ‘Exploration’ and ‘Expressiveness’ were the characteristics with the most positive impact on the scoring output, with coefficients of 0.92 and 0.91, respectively. Furthermore, the number of used timbres while creating the performances is also correlated to the final CSI score. This correlation may be explained by the fact that while improvising, the participants that explored a greater number of different timbres were possibly more engaged to the tool, thus exploring new possibilities and perceiving a greater level of creativity support. The number of used timbres also presented a significant correlation to four of the five measured CSI attributes: Results Worth Effort (0.29), Exploration (0.21), Expressiveness (0.26), and Immersion (0.26). In the same direction, the number of tracks also presents a significant correlation with the ‘Immersion’ level perceived by users (0.25), indicating the when creating more complex performances users tend to feel more immersed.

The significant correlation between the level of ‘Enjoyment’ and the ‘Creativity Level’, which represents the result from the Divergent Thinking Test applied to participants, must also be discussed. The coefficient association (0.27) can be interpreted in a sense where people with higher levels of divergent thinking capability and to think creatively are more likely to feel entertained when using the proposed tool. Although we need more evidence, we can use this information to help identify the target audience for this category of applications.

5.4.1 Sound vs. Visual Feedback

When exploring how the visual feedback impacted on users creativity, we were explicitly interested in comparing the *AR* and *SO* versions, attempting to understand the benefits of the virtual strokes for enhancing creative characteristics. As observed in Table 5.2 and detailed on Subsection 5.3.1, the results from CSI show that the AR mode presented significantly higher levels regarding *Results Worth Effort*, *Exploration*, and *Expressiveness* (14.8%, 21.4%, and 24.9% higher, respectively) creative attributes, as well as for the overall *CSI Score* (18% higher).

Figure 5.9: The figure presents the perceived influence that both drawing and sound outputs had over participants while creating performances with *Musical Brush*. It is used a 5-points Likert scale where 1 means "Strongly Disagree" and 5 means "Strongly Agree".



When asked about the impact that sound and drawings had on their performances, participants tended to respond that the first was a little more crucial in the result. Of the responses, 89% of participants " Agree " or " Totally Agree " who were influenced by the sound during the creation of the performances, while as for the influence of the design on the performances, this percentage decreases to 69% (see Figure 5.9).

Analyzing the results summarized from the performances (see Table 5.3) we see that, despite not presenting a significant difference between the two compared modes (*AR* and *SO*), the session length and the number of tracks used were higher on the *AR* version. We believe that the reduced limit on the number of possible tracks (maximum of six) and the high freedom characteristic of the task led to widely spaced execution times between different users, contributing to a non-significant difference of the mentioned attributes. In conclusion, we can confirm our Hypothesis H1, once that despite not being perceived as impacting as the sound, the visual drawings were crucial for significantly enhancing users' creativity in different topics. Furthermore, user feedback regarding the benefits of visual strokes highlights its importance on different aspects, including:

- *Exploration* - *"Its more clear on what I am doing, easier to experiment"*, (P3); *"its nice to have a history of what has been done"*, (P9); *"It is interesting to see my creations on other perspectives"*, (P13); *"...they facilitate the creation of sounds, helping to understand if I want to put the sounds close or not"*, (P14); and *"More possibilities of experimentation by putting together visual strokes with the reproduced music"*, (P21);
- *Immersion* - *"It makes me focus on more than just one sense"*, (P11); *"...give the feeling that the sounds produced are touchable"*, (P12); and *"The visual appeal generates more immersion and stimulates creativity."*;
- *Expressiveness* - *"It becomes another art form, in addition to the music it makes"*, (P2); *"helps to understand what the artist was thinking"*, (P16); *"It helped me to*

> *come up with more ideas. For example, I was wondering what would be the sound if I drew a happy face, or a star..."*, (P17); *"You can try to do actual drawings while playing with the songs and that makes the creation experience much richer, different, and fun"*, (P25); and *"Make music a more visual element"*, (P26).

On the other hand, it is important to note that a few users reported losing focus on sound due to the presence of the visual traces: *"attention ends up being dispersed by having visual elements together with the sound"* (P14); and *"When you can't see the strokes it is easier to get focused on using movement as the only input..."*, (P25).

5.4.2 Two-dimensional vs. Three-dimensional

Another important condition of our user study was the exploration of how the different types of interactions affected creativity. Notably, our goal was to discover whether this increase in the number of interaction dimensions (from 2D to 3D) would impact positively in the support of creativity.

Contrary to our expectations in H2, the obtained results considering aspects related to the creativity support, measured by Q2 and Q3, were not significantly different between the *2D* and *3D* conditions. When asked about the negative points of the *3D* interactions, users mentioned the difficulties of controlling accurately: *"Less accurate in order to compose drawings or music"*, (P11); *"it is harder to reach the desired note"*, (P19); and *"less precision, since it is hard to control the device rotation and motion"*, (P24). On the other hand, concerning the benefits of *3D* the users highlighted how the third dimension can increase the possibilities of exploration and expressiveness: *"greater space to be creative"*, (P1); *"you have more freedom and available options to create"*, (P14); and *"more possibilities for experimentation"*, (P21);

As expected in H3, the results from Table 5.2 evidence how the 2D version provides more user satisfaction when analyzing the *Results Worth Effort* aspect. This outcome may be connected to the fact that, differently from all other compared versions, participants were allowed to stay still while performing, without the need of moving around, once that all interactions were related to touch gestures on the device screen. This lower physical demand may be noted in some comments when asked about the advantages of the 2D: *"Everything is at one place, no need to move around"*, (P2); *"I could use while sitting, without much effort..."*, (P10); and *"Being seated gives more stability and confidence* *when drawing the strokes"*, (P25). The ease of use due to the simpler interactions complexity and reduced operation space can be seen as an aspect that impacts the exploration of ideas: *"It was easier to understand where the limits of the tones were"*, (P4); *"access to all frequencies quickly"*, (P8); and *"with the limited environment it is easily visible the possibilities"*, (P9).

A negative aspect highlighted participants was that the 2D version failed in terms of *Enjoyability*, providing a less fun interaction: *"It could be boring after a while"*, (P5); *"Less playful and interesting experience"*, (P11); *"Not so much fun"*, (P17); and *"Less fun"*, (P24). The problem of visual pollution due to its reduced space and overlapping of strokes was also mentioned: *"It can get tight on the screen with all the different effects"*, (P1); and *"Limited space for insertion of new points. On longer tracks, dots may overlap and difficult visualization"*, (P6).

5.4.3 Augmented Reality

The comparison between AR and 3D versions was performed within a more exploratory approach. Furthermore, we acknowledge that comparing a real environment with regular objects against a virtual one created with no visual appeal is a bit unfair.

Interestingly, despite presenting an environment with no objects or visual elements, the 3D was the version in which participants moved the most, with an average distance of 8.57 meters for each session. We believe that this may be related to two different conditions: (i) participants were motivated to explore a new environment that was not previously known (see Figure 5.2b); (ii) the tests were performed indoor, reducing the exploration of the environment. On the other hand, the AR version presented higher results for each CSI attribute if compared to the 3D version (see Table 5.2). The AR interaction mode was also chosen as the most preferred version, among the user feedback, the interaction with the real environment while performing was the positive point most highlighted: *"It is more fun to be able to move around the room and create things everywhere"*, (P5); *"It is interesting to interact with the real environment around me to draw"*, (P12); *"be able to see the music around me"*, (P13); and *"Having the real world can bring inspiration to try things you wouldn't do normally, also is fun to play with your surroundings"*, (P25).

5.5 Summary

In a comparative study between four distinct conditions (AR, SO, 3D, and 2D), we observed that the presence of visual elements through drawings contributed significantly to some of the measured creativity related characteristics. In general, 3D interactions were more fun and offered a wider range of different exploration alternatives, while 2D interactions were simpler and required less from users to manage. The tool presented a high overall score related to the support of creativity and was mainly used focusing on the exploration and expressiveness of ideas. A limitation of the proposed prototype application, however, was the difficulty of creating some concrete and pleasant sound results. This is mainly caused by the still non-complex sound generation system, which only presents four different waveform timbres and enables users to control just a few sound characteristics (amplitude, pitch, timbre, and delay effect). A more elaborated sound mapping would possibly provide several new possibilities for the improvisation process.

6 CONCLUSIONS

In this work, in an effort to extend discussions regarding the potential of drawing-based musical interfaces in the support of creativity, we developed a novel application that makes use of AR to combine music with drawings. Experiments were made in order to evaluate the proposed interface, as well as to check which tool characteristics are capable of enhancing creativity-related attributes of users. Our main motivation was to explore how drawing-based musical applications can act as CSTs and understand the benefits of our 3D immersive approach if compared to traditional 2D works.

6.1 Contributions

We attempted to design our application following guidelines for real-time musical controllers (HUNT; KIRK, 2000), immersive instruments (ROESNER et al., 2014; SERAFIN et al., 2016), and CSTs (SHNEIDERMAN et al., 2006). The result, named *Musical Brush*, is an iOS application currently available for download at the App Store[1]. The main idea behind the development of this new interface was the conception of a novel drawing-based musical application that combines music improvisation and drawing in an AR portable immersive experience.

A first user evaluation was conducted to collect overview feedback regarding the designed application and its interactions. The main focus here was the exploration of the four relevant characteristics of musical controllers, according to Orio, Schnell and Wanderley (2001): *"Learnability", "Explorability", "Feature Controllability"* and *"Timing Controllability"*. Surprisingly, some interactions were not perceived as intuitive as expected. Examples include the misunderstanding that sliding the finger on the SmartScreen had some effect, and difficulties in controlling delay effect and amplitude, with the latter showing high reproduction error rates if compared to pitch or timbre. Even so, the application was described as very engaging and enjoyable by the participants, that regardless of musical background, were able to quickly create simple performances. The visual output represented by strokes in AR was the most impacting feature for the users, describing them as appealing and motivational in several aspects. The feedback collected during this first user experiment guided us to perform a second analysis focused on exploring the effectiveness of *Musical Brush* concerning the support of creativity.

[1] <https://apps.apple.com/br/app/musical-brush/id1440590190?l=en>

In this second user study, we focused on exploring the effectiveness of our implementation concerning the support of creativity. More specifically, we were interested in three main aspects: (1) *Is the design of Musical Brush successful in supporting creativity?*; (2) *What aspects of creativity are impacted most?*; and (3) *What are the key features that impact substantially on this support?*. In a comparative study between four different variations of the tool, we investigated their relationship to creativity-related attributes. As expected due to the importance of the visual strokes in user engagement, the AR version presented significantly better results when compared to the SO version on several CSI measured attributes, including *Results Worth Effort*, *Exploration*, and *Expressiveness*, presenting an overall CSI score of 78.4. On the other hand, the 2D version surprisingly presented results quite similar to the AR version when observing the CSI outcomes. We hypothesize that by observing collected data, especially results regarding *Results Worth Effort* and subjective feedback, we identify that the no need for physical movements to use the 2D version collaborated for a more comfortable and pleasant experience. Furthermore, performance characteristics such as the number of tracks and timbres used are positively related to the perceived level of immersion and expressiveness, while the level of enjoyment is connected to the capacity of participants to think creatively.

Finally, we contribute to the investigation of creativity enhancement by providing results related to the evaluation of *Musical Brush* and its different variation versions. The outcome of this study follows the CSI survey methodology and the overall results can be used as a baseline for further works and comparisons with other applications.

6.2 Future Works

Future works include the improvement of *Musical Brush* based on the user studies participant's feedback, especially concerning the sounds produced by the tool, and further testing under different conditions, including distinct timbres and scenarios. We believe that the use of more realistic instrument-like sounds would impact positively the enjoyability of the application. Long term tests exploring the portability of *Musical Brush* by using it on different locations (eg.: different places in a city, touristic points) would also be important to understand how different outdoor environments can impact users creativity on an AR experience.

Besides, despite being one of the key aspects used by CSI in the measurement of creativity support, collaboration has not been explored within the scope of this project.

The study by Sawyer and Dezutter (2009) brings an interesting analysis of *'distributed creativity'* concerning the creation of collective products by groups of individuals in a collaborative process. Thereby, we propose further investigation on the impact of collaboration on the next version of *Musical Brush*, possibly comparing creativity support results with the first version and with different levels of collaboration. Different methods of collaboration could be explored in this sense, either through the co-creation of performances by different individuals or using some machine learning method to assist the performance creations (MARTIN; TORRESEN, 2018).

Finally, we encourage further studies of alternative proposals and provide in this work multiple results which can be used as baselines for future comparisons regarding the ability to support creativity through drawing-based musical interfaces.

6.3 Achievements and Publications

Part of this dissertation work was developed at the University of Oslo (UiO), where I worked as a researcher for one year during an exchange program in partnership between the Federal University of Rio Grande do Sul (UFRGS) and UiO. The program, funded by the ROBIN COINMAC project, was coordinated and only possible thanks to Prof. Dante Augusto Conte Barone (UFRGS) and Prof. Jim Torresen (UiO), who cooperated for the collaboration of the executed activities. At the University of Oslo, Dr. Charles P. Martin also corroborated for the project by discussing ideas and supervising the development of the Musical Brush prototype.

Below are listed the publications made during the master's period, which are indirectly or directly related to the dissertation:

(**Best Poster - Honorable Mention**)
R. Valer, R. Schramm and L. Nedel, **"Musical Brush: Exploring Creativity in an AR-based Tool Combining Music and Drawing Generation,"** 2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), Atlanta, GA, USA, 2020, pp. 634-635, doi: 10.1109/VRW50115.2020.00168.

(**3DUI Contest Winner**)
A. Calepso et al., **"3DUI and the Phantom Limb: Multisensory Experience for Embodiment of Amputation,"** 2020 IEEE Conference on Virtual Reality and 3D User In-

terfaces Abstracts and Workshops (VRW), Atlanta, GA, USA, 2020, pp. 517-518, doi: 10.1109/VRW50115.2020.00110.

Valer R., Schramm R., Nedel L., Martin C.P., Torresen J. (2020) **Musical Brush: Exploring Creativity Through an AR-Based Tool for Sketching Music and Drawings**. In: Magnenat-Thalmann N. et al. (eds) Advances in Computer Graphics. CGI 2020. Lecture Notes in Computer Science, vol 12221. Springer, Cham. https://doi.org/10.1007/978-3-030-61864-3_11

REFERENCES

BARBOSA, J. et al. Illusio: A drawing-based digital music instrument. In: **Proceedings of the International Conference on New Interfaces for Musical Expression**. [S.l.: s.n.], 2013.

BENEDETTI, L. et al. Painting with Bob: Assisted Creativity for Novices. In: **Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology**. New York, NY, USA: ACM, 2014. (UIST '14), p. 419–428. ISBN 978-1-4503-3069-5. Available from Internet: <http://doi.acm.org/10.1145/2642918.2647415>.

BERRY, R. et al. The augmented composer project: The music table. In: **Proceedings - 2nd IEEE and ACM International Symposium on Mixed and Augmented Reality, ISMAR 2003**. IEEE Comput. Soc, 2003. p. 338–339. ISBN 0769520065. Available from Internet: <http://ieeexplore.ieee.org/document/1240749/>.

BERTHAUT, F. et al. Reflets: Combining and revealing spaces for musical performances. In: . [S.l.: s.n.], 2015.

BILDA, Z.; DEMIRKAN, H. An insight on designers' sketching activities in traditional versus digital media. **Design Studies**, Elsevier, v. 24, n. 1, p. 27–50, 1 2003. ISSN 0142-694X. Available from Internet: <https://www.sciencedirect.com/science/article/pii/S0142694X02000327>.

BLAINE, T.; FELS, S. Collaborative Musical Experiences for Novices. **Journal of New Music Research**, v. 32, n. 4, p. 411–428, 2003. ISSN 1744-5027. Available from Internet: <https://www.tandfonline.com/action/journalInformation?journalCode=nnmr20>.

CARROLL, E. A.; LATULIPE, C. The creativity support index. In: **Proceedings of the 27th international conference extended abstracts on Human factors in computing systems - CHI EA '09**. New York, New York, USA: ACM Press, 2009. p. 4009. ISBN 9781605582474. Available from Internet: <http://portal.acm.org/citation.cfm?doid=1520340.1520609>.

CARROLL, E. A.; LATULIPE, C. Triangulating the Personal Creative Experience: Self-report, External Judgments, and Physiology. In: **Proceedings of Graphics Interface 2012**. Toronto, Ont., Canada, Canada: Canadian Information Processing Society, 2012. (GI '12), p. 53–60. ISBN 978-1-4503-1420-6. Available from Internet: <http://dl.acm.org/citation.cfm?id=2305276.2305286>.

CHERRY, E.; LATULIPE, C. Quantifying the Creativity Support of Digital Tools through the Creativity Support Index. **ACM Transactions on Computer-Human Interaction**, ACM, v. 21, n. 4, p. 1–25, 6 2014. ISSN 10730516. Available from Internet: <http://dl.acm.org/citation.cfm?doid=2633907.2617588>.

CHERRY, E. et al. Creativity factor evaluation: towards a standardized survey metric for creativity support. In: . [S.l.: s.n.], 2009. p. 127–136.

CHIANG, C.-W. et al. Birds on Paper: An Alternative Interface to Compose Music by Utilizing Sketch Drawing and Mobile Device. In: **Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction**.

New York, NY, USA: ACM, 2012. (TEI ’12), p. 201–204. ISBN 978-1-4503-1174-8. Available from Internet: <http://doi.acm.org/10.1145/2148131.2148175>.

CHRISTENSEN, P. R. et al. Alternate uses. **Beverly Hills: Sheridan Psychological Services**, 1960.

COOK, P. 2001: Principles for Designing Computer Music Controllers. In: **A NIME Reader**. [S.l.]: Springer, 2017. p. 1–13.

DIX, A. **Human-computer interaction**. [S.l.]: Pearson/Prentice-Hall, 2004. 834 p. ISBN 9780130461094.

DUNN, O. J. Multiple comparisons using rank sums. **Technometrics**, Taylor & Francis Group, v. 6, n. 3, p. 241–252, 1964.

ENO, P. C. B. **Bloom Open Space – A mixed reality installation by Brian Eno and Peter Chilvers**. 2018. Available from Internet: <http://bloomopenspace.com/>.

ESSL, G.; WANG, G.; ROHS, M. **Developments and Challenges turning Mobile Phones into Generic Music Performance Platforms**. 2008. Available from Internet: <https://www.semanticscholar.org/paper/Developments-and-Challenges-turning-Mobile-Phones-Essl-Wang/d3576ba7e971f1c999648b96f3072a2b50a16cc9>.

FARBOOD, M.; PASZTOR, E.; JENNINGS, K. Hyperscore: a graphical sketchpad for novice composers. **IEEE Computer Graphics and Applications**, v. 24, n. 1, p. 50–54, 1 2004. ISSN 0272-1716. Available from Internet: <http://ieeexplore.ieee.org/document/1255809/>.

FELS, S.; MASE, K. Iamascope: a graphical musical instrument. **Computers & Graphics**, v. 23, n. 2, p. 277–286, 4 1999. ISSN 00978493. Available from Internet: <http://linkinghub.elsevier.com/retrieve/pii/S0097849399000370>.

FISCHER, G. Social creativity: turning barriers into opportunities for collaborative design. In: ACM. **Proceedings of the eighth conference on Participatory design: Artful integration: interweaving media, materials and practices-Volume 1**. [S.l.], 2004. p. 152–161.

FLORIDA, R. L. **The flight of the creative class : the new global competition for talent**. [S.l.]: HarperBusiness, 2005. 326 p. ISBN 006075690X.

FRANÇOISE, J.; Jules. Gesture–sound mapping by demonstration in interactive music systems. In: **Proceedings of the 21st ACM international conference on Multimedia - MM ’13**. New York, New York, USA: ACM Press, 2013. p. 1051–1054. ISBN 9781450324045. Available from Internet: <http://dl.acm.org/citation.cfm?doid=2502081.2502214>.

FRICH, J. et al. Mapping the Landscape of Creativity Support Tools in HCI. In: **Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems**. New York, NY, USA: ACM, 2019. (CHI ’19), p. 389:1–389:18. ISBN 978-1-4503-5970-2. Available from Internet: <http://doi.acm.org/10.1145/3290605.3300619>.

GARCÍA, C. G. et al. Swift vs. objective-c: A new programming language. **IJIMAI, ISSN-e 1989-1660, Vol. 3, Nº. 3, 2015, págs. 74-81**, ImaI-Software, v. 3, n. 3, p. 74–81, 2015. Available from Internet: <https://dialnet.unirioja.es/servlet/articulo?codigo=5574309>.

GARCIA, J. et al. **PaperTonnetz: Supporting Music Composition with Interactive Paper**. [S.l.], 2012. v. 2013-April, 3051–3054 p. Available from Internet: <http://www.cycling74.com>.

GARCIA, J. et al. InkSplorer: Exploring Musical Ideas on Paper and Computer. 5 2011. Available from Internet: <https://hal.inria.fr/inria-00600083/>.

GELINECK, S. et al. Virtual Reality Instruments capable of changing Dimensions in Real-time. **Proceedings Enactive**, 2005.

GRIFFIN, G.; JACOB, R. Priming Creativity Through Improvisation on an Adaptive Musical Instrument. In: **Proceedings of the 9th ACM Conference on Creativity & Cognition**. New York, NY, USA: ACM, 2013. (C&C '13), p. 146–155. ISBN 978-1-4503-2150-1. Available from Internet: <http://doi.acm.org/10.1145/2466627.2466630>.

GUILFORD, J. P. The structure of intellect. **Psychological bulletin**, American Psychological Association, v. 53, n. 4, p. 267, 1956.

GUILFORD, J. P. The nature of human intelligence. McGraw-Hill, 1967.

HALPERN, M. K. et al. MoBoogie: Creative Expression Through Whole Body Musical Interaction. In: **Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11**. New York, New York, USA: ACM Press, 2011. p. 557. ISBN 9781450302289. Available from Internet: <http://dl.acm.org/citation.cfm?doid=1978942.1979020>.

HOCEVAR, D. Measurement of creativity: Review and critique. **Journal of Personality assessment**, Taylor & Francis, v. 45, n. 5, p. 450–464, 1981.

HUNT, A.; KIRK, R. Mapping strategies for musical performance. **Trends in gestural control of music**, v. 21, n. 2000, p. 231–258, 2000.

HUNT, A.; WANDERLEY, M. M. Mapping performer parameters to synthesis engines. **Organised Sound**, v. 7, n. 02, 8 2002. ISSN 1355-7718. Available from Internet: <http://www.journals.cambridge.org/abstract_S1355771802002030>.

ICHINO, J. et al. Vuzik. In: . [S.l.: s.n.], 2015. p. 240–249.

JORDÀ, S. et al. The reacTable. In: **Proceedings of the 1st international conference on Tangible and embedded interaction - TEI '07**. New York, New York, USA: ACM Press, 2007. p. 139. ISBN 9781595936196. Available from Internet: <http://portal.acm.org/citation.cfm?doid=1226969.1226998>.

KARJALAINEN, M. et al. Virtual Air Guitar. **Journal of the Audio Engineering Society**, Audio Engineering Society, v. 54, n. 10, p. 964–980, 10 2006. Available from Internet: <http://www.aes.org/e-lib/browse.cfm?elib=13884>.

KEELE, S. W. **Attention and human performance**. Goodyear Pub. Co, 1973. 184 p. ISBN 0876200420. Available from Internet: <https://books.google.no/books/about/Attention_and_Human_Performance.html?id=N-ZzQgAACAAJ&redir_esc=y>.

KIM, J. et al. Motif: Supporting Novice Creativity Through Expert Patterns. In: **Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems**. New York, NY, USA: ACM, 2015. (CHI '15), p. 1211–1220. ISBN 978-1-4503-3145-6. Available from Internet: <http://doi.acm.org/10.1145/2702123.2702507>.

KIM, K. L.; YEO, W. S. Griddy: a drawing based music composition system with multi-layered structure. In: **ICMC**. [S.l.: s.n.], 2014.

KNÖRIG, A.; MÜLLER, B.; WETTACH, R. Articulated paint: musical expression for non-musicians. In: ACM. **Proceedings of the 7th international conference on New interfaces for musical expression**. [S.l.], 2007. p. 384–385.

KRUSKAL, W. H.; WALLIS, W. A. Use of Ranks in One-Criterion Variance Analysis. **Journal of the American Statistical Association**, Taylor & Francis, v. 47, n. 260, p. 583–621, 1952. Available from Internet: <https://amstat.tandfonline.com/doi/abs/10.1080/01621459.1952.10483441>.

LAURENZO, T.; RODRÍGUEZ, E.; CASTRO, J. F. **YARMI : an Augmented Reality Musical Instrument Tomás Laurenzo**. [S.l.], 2009. 268–269 p. Available from Internet: <http://www.universidad.edu.uy>.

LI, Y.; SONG, Y.-Z.; GONG, S. Sketch Recognition by Ensemble Matching of Structured Features. In: **Procedings of the British Machine Vision Conference 2013**. British Machine Vision Association, 2013. p. 1–35. ISBN 1-901725-49-9. Available from Internet: <http://www.bmva.org/bmvc/2013/Papers/paper0035/index.html>.

LOHNER, H. The UPIC System: A User's Report. **Computer Music Journal**, v. 10, n. 4, p. 42, 24 1986. ISSN 01489267. Available from Internet: <https://www.jstor.org/stable/3680095?origin=crossref>.

LUBART, T. I. Product-centered self-evaluation and the creative process. **Unpublished doctoral dissertation, Yale University, New Haven, CT**, 1994.

LUGT, R. der. How sketching can affect the idea generation process in design group meetings. **Design studies**, Elsevier, v. 26, n. 2, p. 101–122, 2005.

LYONS, M.; FELS, S. Creating new interfaces for musical expression. In: **SIGGRAPH Asia 2013 Courses on - SA '13**. New York, New York, USA: ACM Press, 2013. p. 1–164. ISBN 9781450326315. Available from Internet: <http://dl.acm.org/citation.cfm?doid=2542266.2542283>.

LYONS, M. J. **The Mouthesizer**. [S.l.], 2001. Available from Internet: <http://www.mic.atr.co.jp/~mlyons/mouthesizer.html>.

MÄKI-PATOLA, T. et al. **Experiments with Virtual Reality Instruments**. [S.l.], 2004. Available from Internet: <http://www.nime.org/proceedings/2005/nime2005_011.pdf>.

MARTIN, C. et al. Intelligent agents and networked buttons improve free-improvised ensemble music-making on touch-screens. In: **Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems**. New York, NY, USA: Association for Computing Machinery, 2016. (CHI '16), p. 2295–2306. ISBN 9781450333627. Available from Internet: <https://doi.org/10.1145/2858036.2858269>.

MARTIN, C. P.; TØRRESEN, J. MicroJam: An App for Sharing Tiny Touch-Screen Performances. In: AALBORG UNIVERSITY COPENHAGEN. **Proceedings of the International Conference on New Interfaces for Musical Expression**. [S.l.], 2017. p. 495–496.

MARTIN, C. P.; TORRESEN, J. Robojam: A musical mixture density network for collaborative touchscreen interaction. In: LIAPIS, A.; CARDALDA, J. J. R.; EKÁRT, A. (Ed.). **Computational Intelligence in Music, Sound, Art and Design**. Cham: Springer International Publishing, 2018. p. 161–176. ISBN 978-3-319-77583-8.

MARTIN, C. P.; TORRESEN, J. **Data Driven Analysis of Tiny Touchscreen Performance with MicroJam**. 2019.

MIRANDA, E. R.; WANDERLEY, M. M. **New digital musical instruments: control and interaction beyond the keyboard**. [S.l.]: AR Editions, Inc., 2006.

MIYASHITA, T. et al. An Augmented Reality museum guide. In: **2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality**. IEEE, 2008. p. 103–106. ISBN 978-1-4244-2840-3. Available from Internet: <http://ieeexplore.ieee.org/document/4637334/>.

MULDER, A. G. E. **Design of virtual three-dimensional instruments for sound control.** [S.l.]: Simon Fraser University, 1999.

Narzt et al. Pervasive information acquisition for mobile AR-navigation systems. In: **Proceedings DARPA Information Survivability Conference and Exposition MCSA-03**. IEEE, 2003. p. 13–20. ISBN 0-7695-1995-4. Available from Internet: <http://ieeexplore.ieee.org/document/1240763/>.

NAYLOR, T. D.; FLORIDA, R. The Rise of the Creative Class: And How It's Transforming Work, Leisure, Community and Everyday Life. **Canadian Public Policy / Analyse de Politiques**, v. 29, n. 3, p. 378, 9 2003. ISSN 03170861. Available from Internet: <https://www.jstor.org/stable/3552294?origin=crossref>.

NELSON, P. **The UPIC system as an instrument of learning**. [S.l.], 1997. Available from Internet: <https://pdfs.semanticscholar.org/3425/fc400cd2c4cf1aa9ff7231ef2a541e234c62.pdf>.

NYMOEN, K. et al. **Searching for Cross-Individual Relationships between Sound and Movement Features using an SVM Classifier**. [S.l.], 2010. Available from Internet: <http://rapid-i.com/>.

OCHSE, R. A.; OCHSE, R.; OCHSE, R. **Before the gates of excellence: The determinants of creative genius**. [S.l.]: CUP Archive, 1990.

ORIO, N.; SCHNELL, N.; WANDERLEY, M. M. Input devices for musical expression: borrowing tools from HCI. In: **Proceedings of the 2001 conference on New interfaces for musical expression**. [S.l.: s.n.], 2001. p. 1–4.

PARADISO, J. Electronic music: new ways to play. **IEEE Spectrum**, v. 34, n. 12, p. 18–30, 12 1997. ISSN 0018-9235. Available from Internet: <http://ieeexplore.ieee.org/document/642965/>.

PARADISO, J. A. **The Brain Opera Technology: New Instruments and Gestural Sensors for Musical Interaction and Performance**. [S.l.], 1998. Available from Internet: <http://cba.mit.edu/docs/papers/98.3.JNMR_Brain_Opera.pdf>.

PARADISO, J. A.; O'MODHRAIN, S. Current Trends in Electronic Music Interfaces. Guest Editors' Introduction. **Journal of New Music Research**, v. 32, n. 4, p. 345–349, 2003. ISSN 1744-5027. Available from Internet: <https://www.tandfonline.com/action/journalInformation?journalCode=nnmr20>.

POUPYREV, I. et al. Augmented groove: Collaborative jamming in augmented reality. In: **ACM SIGGRAPH 2000 Conference Abstracts and Applications**. [S.l.: s.n.], 2000. v. 17, n. 7, p. 77.

POUPYREV, I. et al. New interfaces for musical expression. In: **CHI '01 extended abstracts on Human factors in computing systems - CHI '01**. New York, New York, USA: ACM Press, 2001. p. 491. ISBN 1581133405. Available from Internet: <http://portal.acm.org/citation.cfm?doid=634067.634348>.

RASAMIMANANA, N. et al. The urban musical game: using sport balls as musical interfaces. p. –, 2012. Available from Internet: <https://hal.archives-ouvertes.fr/hal-01106959/>.

RENAUD, A.; CHARBONNIER, C.; CHAGUÉ, S. 3DinMotion A Mocap Based Interface for Real Time Visualisation and Sonification of Multi-User Interactions. In: **NIME**. [S.l.: s.n.], 2014. p. 495–496.

ROESNER, F. et al. Augmented reality: Hard Problems of Law and Policy. In: **Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing Adjunct Publication - UbiComp '14 Adjunct**. New York, New York, USA: ACM Press, 2014. p. 1283–1288. ISBN 9781450330473. Available from Internet: <http://dl.acm.org/citation.cfm?doid=2638728.2641709>.

ROSSING, T. D. **Springer handbook of acoustics**. [S.l.]: Springer, 2007. 1182 p. ISBN 0387304460.

ROVAN, J. B. et al. Instrumental gestural mapping strategies as expressivity determinants in computer music performance. In: CITESEER. **Kansei, The Technology of Emotion. Proceedings of the AIMI International Workshop**. [S.l.], 1997. p. 68–73.

SAWYER, R. K.; DEZUTTER, S. Distributed Creativity: How Collective Creations Emerge From Collaboration. 2009.

SCHIEWE, A.; ANSTOOTS, M.; KRÜGER, J. State of the Art in Mobile Volume Rendering on iOS Devices. In: BERTINI, E.; KENNEDY, J.; PUPPO, E. (Ed.).

Eurographics Conference on Visualization (EuroVis) - Short Papers. [S.l.]: The Eurographics Association, 2015.

SCHRAMM, R.; NUNES, H. D. S.; JUNG, C. R. Audiovisual Tool for Solfège Assessment. **ACM Transactions on Multimedia Computing, Communications, and Applications**, v. 13, n. 1, p. 1–21, 12 2016. ISSN 15516857. Available from Internet: <http://dl.acm.org/citation.cfm?doid=3012406.3007194>.

SERAFIN, S. et al. Virtual Reality Musical Instruments: State of the Art, Design Principles, and Future Directions. **Computer Music Journal**, MIT Press One Rogers St., Cambridge, MA 02142-1209 USA journals-info@mit.edu, v. 40, n. 3, p. 22–40, 9 2016. ISSN 0148-9267. Available from Internet: <http://www.mitpressjournals.org/doi/10.1162/COMJ_a_00372>.

SHAPIRO, S. S.; WILK, M. B. An analysis of variance test for normality (complete samples). **Biometrika**, JSTOR, v. 52, n. 3/4, p. 591–611, 1965.

SHNEIDERMAN, B.; Ben. Creativity support tools. **Communications of the ACM**, ACM, v. 45, n. 10, p. 116–120, 10 2002. ISSN 00010782. Available from Internet: <http://portal.acm.org/citation.cfm?doid=570907.570945>.

SHNEIDERMAN, B.; Ben. Creativity support tools: accelerating discovery and innovation. **Communications of the ACM**, ACM, v. 50, n. 12, p. 20–32, 12 2007. ISSN 00010782. Available from Internet: <http://portal.acm.org/citation.cfm?doid=1323688.1323689>.

SHNEIDERMAN, B. et al. **Creativity Support Tools: Report From a U.S. National Science Foundation Sponsored Workshop**. [S.l.], 2006. v. 20, n. 2, 61–77 p. Available from Internet: <http://www.cs.umd.edu/hcil/CST>.

SHNEIDERMAN, B.; PLAISANT, C. **Designing the user interface : strategies for effective human-computer interaction**. [S.l.]: Addison-Wesley, 2010. 606 p. ISBN 0321537351.

SPEARMAN, C. The Proof and Measurement of Association Between Two Things. **The American Journal of Psychology**, v. 15, p. 72–101, 1904.

STERNBERG, R. J. **Handbook of creativity**. [S.l.]: Cambridge University Press, 1999.

SULLIVAN, A.; ELADHARI, M. P.; COOK, M. Tarot-based Narrative Generation. In: **Proceedings of the 13th International Conference on the Foundations of Digital Games**. New York, NY, USA: ACM, 2018. (FDG ’18), p. 54:1–54:7. ISBN 978-1-4503-6571-0. Available from Internet: <http://doi.acm.org/10.1145/3235765.3235819>.

THIEBAUT, J.-B.; HEALEY, P. G. T.; BRYAN-KINNS, N. Drawing Electroacoustic Music. In: **ICMC**. [S.l.: s.n.], 2008.

TSANDILAS, T.; LETONDAL, C.; MACKAY, W. Musink: Composing Music through Augmented Drawing. **Conference on Human Factors in Computing Systems - Proceedings**, p. 819–828, 2009.

WANDERLEY, M.; BATTIER, M. Trends in gestural control of music. In: IRCAM. [S.l.], 2000.

WANDERLEY, M.; DEPALLE, P. Gestural Control of Sound Synthesis. **Proceedings of the IEEE**, v. 92, n. 4, p. 632–644, 4 2004. ISSN 0018-9219. Available from Internet: <http://ieeexplore.ieee.org/document/1278687/>.

WANDERLEY, M. M.; DEPALLE, P. Gestural Control of Sound Synthesis. 2004. Available from Internet: <http://haptic.mech.mwu.edu/.>

WANDERLEY, M. M.; ORIO, N. **Evaluation of input devices for musical expression: Borrowing tools from HCI**. [S.l.], 2002. v. 26, n. 3, 62–76 p. Available from Internet: <http://www.nime.org/proceedings/2001/nime2001_015.pdf>.

WANG, G. Designing Smule's Ocarina: The iPhone's Magic Flute. In: **NIME**. [S.l.: s.n.], 2009. p. 303–307.

WANG, G. **Principles of Visual Design for Computer Music**. [S.l.], 2014. Available from Internet: <https://www.researchgate.net/profile/Ge_Wang9/publication/265162871_Principles_of_Visual_Design_for_Computer_Music/links/5401475e0cf23d9765a491a9.pdf>.

WANG, G.; ESSL, G.; PENTTINEN, H. Do mobile phones dream of electric orchestras? **International Computer Music Conference, ICMC 2008**, p. 29, 2008. Available from Internet: <http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.216.7430>.

WANG, H.-C.; COSLEY, D.; FUSSELL, S. R. Idea Expander: Supporting Group Brainstorming with Conversationally Triggered Visual Thinking Stimuli. In: **Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work**. New York, NY, USA: ACM, 2010. (CSCW '10), p. 103–106. ISBN 978-1-60558-795-0. Available from Internet: <http://doi.acm.org/10.1145/1718918.1718938>.

WEINBERG GIL, . Interconnected musical networks : bringing expression and thoughtfulness to collaborative group playing. Massachusetts Institute of Technology, 2003. Available from Internet: <https://dspace.mit.edu/handle/1721.1/28287#files-area>.

WEINBERG GIL, . Interconnected musical networks : bringing expression and thoughtfulness to collaborative group playing. Massachusetts Institute of Technology, 2003. Available from Internet: <https://dspace.mit.edu/handle/1721.1/28287>.

WEISER, M. The computer for the 21 st century. **Scientific American**, Scientific American, a division of Nature America, Inc., v. 265, n. 3, p. 94–105, 1991. ISSN 00368733, 19467087. Available from Internet: <http://www.jstor.org/stable/24938718>.

WESSEL, D. L. Timbre Space as a Musical Control Structure. **Computer Music Journal**, v. 3, n. 2, p. 45, 6 1979. ISSN 01489267. Available from Internet: <https://www.jstor.org/stable/3680283?origin=crossref>.

WU, X.; LI, Z.-N. A study of image-based music composition. In: IEEE. **2008 IEEE International Conference on Multimedia and Expo**. [S.l.], 2008. p. 1345–1348.

YOVCHEVA, Z.; BUHALIS, D.; GATZIDIS, C. Smartphone augmented reality applications for tourism. **E-review of tourism research (ertr)**, Bournemouth University, Fern Barrow, Poole, Dorset, BH12 5BB, UK, v. 10, n. 2, p. 63–66, 2012.

ZIELASKO, D. et al. Cirque des bouteilles: The art of blowing on bottles. In: **2015 IEEE Symposium on 3D User Interfaces (3DUI)**. IEEE, 2015. p. 209–210. ISBN 978-1-4673-6886-5. Available from Internet: <http://ieeexplore.ieee.org/document/7131774/>.

Appendices

APPENDIX A — USER STUDY I: PRE-QUESTIONNAIRE

Musical Brush: User Study

This is a user study that aims the evaluation of the Musical Brush interface.

* Required

1. **Name:** *

2. **Age:** *

3. **How many years of music practice do you have?** *
   Mark only one oval.
   - ( ) 0
   - ( ) 1 - 3
   - ( ) 3 - 5
   - ( ) More then 5

4. **What is your expertise level in music?** *
   Mark only one oval.

	1	2	3	4	5	
Beginner	( )	( )	( )	( )	( )	Expert

5. **What is your experience in using smartphones?** *
   Mark only one oval.

	1	2	3	4	5	
Beginner	( )	( )	( )	( )	( )	Expert

6. **What is your experience with other musical apps?** *
   Mark only one oval.

	1	2	3	4	5	
Never used	( )	( )	( )	( )	( )	Expert

APPENDIX B — USER STUDY I: TASKS QUESTIONNAIRE

Task 2

Questions related to the second task: reproducing the timbre, pitch and amplitude of a note.

* Required

1. **How difficult was it to reproduce the PITCH of the notes? ***
   Pitch is the frequency of the played sound and is controlled by moving the phone in vertical axis.
   Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

2. **How difficult was it to auditively compare the TIMBRE of notes? ***
   Timbre distinguishes different types of sound and is controlled by selecting between the 4 different waveforms.
   Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

3. **How difficult was it to reproduce the TIMBRE of the notes? ***
   Timbre distinguishes different types of sound and is controlled by selecting between the 4 different waveforms.
   Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

4. **How difficult was it to auditively compare the AMPLITUDE of notes? ***
   Amplitude is the loudness of sound and is controlled by the pressure of the touch on the screen.
   Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

5. **How difficult was it to reproduce the AMPLITUDE of the notes? ***
   Amplitude is the loudness of sound and is controlled by the pressure of the touch on the screen.
   Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

6. **Explain if you had any difficulty performing this task:**

____
____
____
____
____

Task 3

Questions related to the third task: reproducing performances.

7. **How difficult was it to reproduce the performances? ***
   Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

8. **How difficult was it to reproduce the AMPLITUDE of the performances?** *
Amplitude is the loudness of sound and is controlled by the pressure of the touch on the screen.
Mark only one oval.

	1	2	3	4	5	
Very easy	⬭	⬭	⬭	⬭	⬭	Very difficult

9. **I was influenced by the sound while reproducing the performance.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

10. **I was influenced by the drawing while reproducing the performance.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

11. **Which version of the background camera did you like most (Image showing the real environment x black background x did not perceived any difference)? And why?** *

12. **Explain if you had any difficulty performing this task:**

Task 4

Questions related to the fourth task: creating your own performance.

13. **How satisfied are you with your composition?** *
Mark only one oval.

	1	2	3	4	5	
Not satisfied	⬭	⬭	⬭	⬭	⬭	Very satisfied

14. **I was influenced by the generated sound while composing.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

15. **I was influenced by the generated drawing while composing.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

16. **What was your engagement level while composing?** *
Mark only one oval.

	1	2	3	4	5	
Not engaged	◯	◯	◯	◯	◯	Very engaged

APPENDIX C — USER STUDY I: OVERALL QUESTIONNAIRE

Overall: Musical Brush

Questions related to the interface and features in general.

* Required

1. **What was the difficulty level for learning to use the tool?** *

   Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

2. **What difficulties did you have while learning the instrument?**

   ____
   ____
   ____
   ____
   ____

3. **What was the difficulty level for controlling the pitch?** *

   Pitch is the frequency of the played sound and is controlled by moving the phone in vertical axis.

   Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

4. **What was the difficulty level for controlling the timbre?** *

   Timbre distinguishes different types of sound and is controlled by selecting between the 4 different waveforms.

   Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

5. **What was the difficulty level for controlling the amplitude?** *

   Amplitude is the loudness of sound and is controlled by the pressure of the touch on the screen.

   Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

6. **What was the difficulty level for controlling the delay effect?** *

   Delay effect is controlled by the accelerometer of the device when detected some abrupt motion.

   Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

7. **What difficulties did you have while controlling any of the features?**

   ____
   ____
   ____
   ____
   ____

8. **How easy it was to express rhythms.** *

Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

9. **Movement and sound were tightly connected in time.** *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

10. **About the duration of the performance (8 seconds), I felt that:** *

Mark only one oval.

- ◯ The performance should be longer.
- ◯ The performance should be shorter.
- ◯ The current duration is ok.

11. **How pleasant is to hear the sound generated from the app?** *

Mark only one oval.

	1	2	3	4	5	
Very unpleasant	◯	◯	◯	◯	◯	Very pleasant

12. **In your opinion, what kind of impact did the drawing have on you while composing?**

13. **If you have any extra feedback, please write it here.**

APPENDIX D — USER STUDY II: PRE-QUESTIONNAIRE

Pré-Questionário

Este é um estudo de usuário que visa a compreensão do processo criativo ao usar o Musical Brush como um aplicativo musical.

* Required

Consent for participation in the study

"Musical Brush User Experience Study"

Background and Purpose

This project involves the development of an app for musical composition. As part of this project, we will examine the user experience of working with the system. We will also write a report on this which will be included as part of a joint master's thesis project at the department of informatics at the Federal University of Rio Grande do Sul (UFRGS) and at the University of Oslo (UiO).

What does participation in the project imply?

We wish to interview you regarding your experience of the use of the Musical Brush application. The purpose of this interview is to examine your experience of working with this app; therefore, we wish to use your responses during this study in our report.

You will perform musical tasks and improvisations with a new musical app that uses Augmented Reality technology.

Voluntary participation

Participation in this study is entirely voluntary. If you wish to withdraw, we will refrain from reporting your interview responses. We will not publish performances that you do not want us to. We ask that you participate in this research only if you feel generally comfortable with publishing your performances.

Before the study starts, we ask you to consent to participation in this study, as well as the publishing of your performances on the internet by confirming that you have read and understood the information provided in this form.

Consent

I have read and understood the information provided above and give my consent to participate in this study.

1. **Você concorda com os termos e condições deste estudo?**
Mark only one oval.

( ) Li e entendi as informações fornecidas acima e dou meu consentimento para participar deste estudo.

( ) Eu NÃO quero participar. *Stop filling out this form.*

Informações Pessoais

2. **Nome:** *

3. **Idade:** *

4. **Quantos anos de prática musical você tem?** *
Mark only one oval.

- 0
- 1 - 2
- 3 - 4
- 5+

5. **Quantos aplicativos diferentes que utilizam de Realidade Aumentada você já usou em seu smartphone?** *
Mark only one oval.

- 0
- 1
- 2
- 3
- 4+

6. **Quantos aplicativos diferentes de criação de música você usou no seu smartphone?** *
Mark only one oval.

- 0
- 1
- 2
- 3
- 4+

7. **Você é familiarizado com aplicativos que usam o movimento do smartphone para seu funcionamento?** *
Mark only one oval.

- Yes
- No

8. **Você já usou este aplicativo (Musical Brush) antes?** *
Mark only one oval.

- Yes
- No

APPENDIX E — USER STUDY II: CSI QUESTIONNAIRE

Índice de Suporte à Criatividade

* Required

1. **Fiquei satisfeito com o que obtive do aplicativo.** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Discordo totalmente											Concordo totalmente

2. **Para mim, foi fácil explorar diferentes ideias, opções, designs ou resultados diferentes, usando este aplicativo.** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Discordo totalmente											Concordo totalmente

3. **Eu ficaria feliz em usar este aplicativo regularmente.** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Discordo totalmente											Concordo totalmente

4. **Consegui ser muito criativo ao fazer a atividade com este aplicativo.** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Discordo totalmente											Concordo totalmente

5. **Minha atenção estava totalmente voltada para a atividade e esqueci do aplicativo que estava usando.** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Discordo totalmente											Concordo totalmente

6. **Eu gostei de usar este aplicativo.** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Discordo totalmente											Concordo totalmente

7. **O aplicativo foi útil para permitir que eu acompanhasse diferentes ideias, resultados ou possibilidades.** *
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Discordo totalmente											Concordo totalmente

8. **O que eu pude produzir valeu o esforço que eu tive que fazer para produzi-lo.** *
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Discordo totalmente											Concordo totalmente

9. **O aplicativo me permitiu ser muito expressivo.** *
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Discordo totalmente											Concordo totalmente

10. **Fiquei tão imerso na atividade que esqueci do aplicativo que estava usando.** *
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Discordo totalmente											Concordo totalmente

APPENDIX F — USER STUDY II: CSI POS-QUESTIONNAIRE

Índice de Suporte à Criatividade - Pos

* Required

1. **Ao executar esta tarefa, é mais importante que eu seja capaz de ...** *
   Mark only one oval.
   - Ser criativo e expressivo
   - Produzir resultados que valem o esforço que dedico

2. **Ao executar esta tarefa, é mais importante que eu seja capaz de ...** *
   Mark only one oval.
   - Gostar de usar o aplicativo
   - Ficar imerso na atividade

3. **Ao executar esta tarefa, é mais importante que eu seja capaz de ...** *
   Mark only one oval.
   - Ficar imerso na atividade
   - Produzir resultados que valem o esforço que dedico

4. **Ao executar esta tarefa, é mais importante que eu seja capaz de ...** *
   Mark only one oval.
   - Produzir resultados que valem o esforço que dedico
   - Explorar diferentes ideias, resultados ou possibilidades

5. **Ao executar esta tarefa, é mais importante que eu seja capaz de ...** *
   Mark only one oval.
   - Ser criativo e expressivo
   - Ficar imerso na atividade

6. **Ao executar esta tarefa, é mais importante que eu seja capaz de ...** *
   Mark only one oval.
   - Ser criativo e expressivo
   - Gostar de usar o aplicativo

7. **Ao executar esta tarefa, é mais importante que eu seja capaz de ...** *
   Mark only one oval.
   - Explorar diferentes ideias, resultados ou possibilidades
   - Ficar imerso na atividade

8. **Ao executar esta tarefa, é mais importante que eu seja capaz de ...** *
   Mark only one oval.
   - Produzir resultados que valem o esforço que dedico
   - Gostar de usar o aplicativo

9. **Ao executar esta tarefa, é mais importante que eu seja capaz de ...** *
Mark only one oval.

- Explorar diferentes ideias, resultados ou possibilidades
- Ser criativo e expressivo

10. **Ao executar esta tarefa, é mais importante que eu seja capaz de ...** *
Mark only one oval.

- Explorar diferentes ideias, resultados ou possibilidades
- Gostar de usar o aplicativo

APPENDIX G — USER STUDY II: POS-QUESTIONNAIRE

Pós-Questionário

Este é um questionário sobre sua experiência durante o experimento.

* Required

1. **Apresente os pontos POSITIVOS de ter traços visuais como feedback ao invés de apenas som durante a execução:**

2. **Apresente os pontos NEGATIVOS de ter traços visuais como feedback ao invés de apenas som durante a execução:**

3. **Apresente os pontos POSITIVOS do modo de interação em 2D:**

4. **Apresente os pontos NEGATIVOS do modo de interação em 2D:**

5. **Apresente os pontos POSITIVOS do modo de interação em 3D:**

6. **Apresente os pontos NEGATIVOS do modo de interação em 3D:**

7. **Eu fui influenciado pelo som enquanto criava minha performance.** *
Mark only one oval.

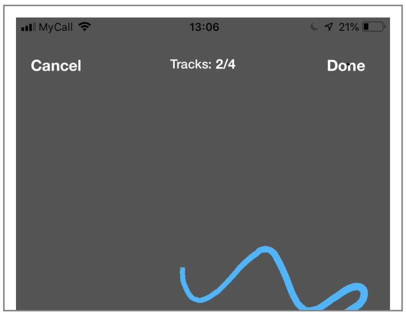
	1	2	3	4	5	
Discordo totalmente	⬭	⬭	⬭	⬭	⬭	Concordo totalmente

8. **Eu fui influenciado pelo desenho enquanto criava minha performance.** *
Mark only one oval.

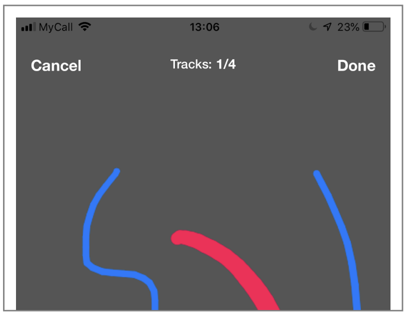
	1	2	3	4	5	
Discordo totalmente	⬭	⬭	⬭	⬭	⬭	Concordo totalmente

9. **Qual versão da ferramenta você MAIS gostou?** *

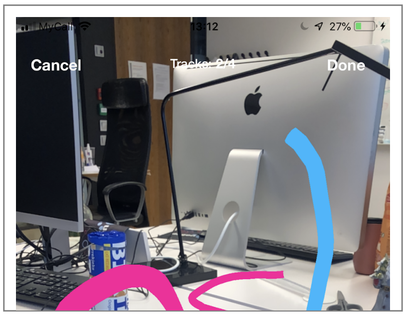
Mark only one oval.



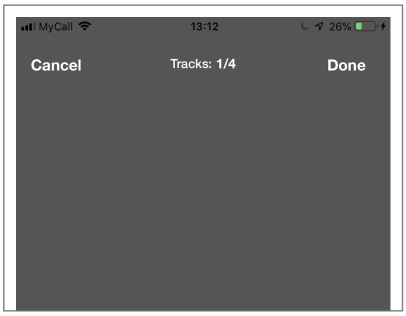
( ) 3D



( ) 2D



( ) 3D AR



( ) Audio Only

10. **Por que você considera esta a melhor versão?**

____

____

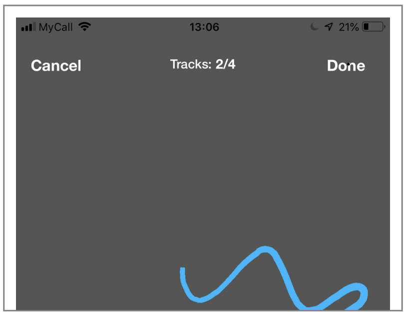
____

____

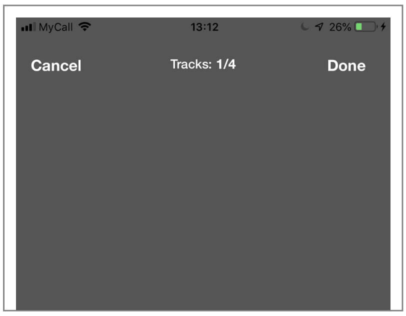
____

11. **Qual versão da ferramenta você MENOS gostou?** *

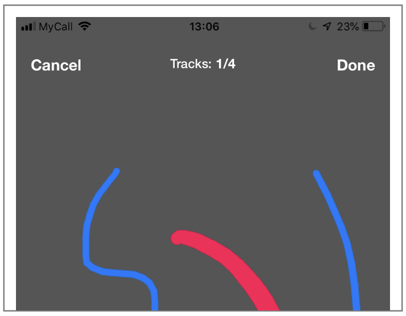
Mark only one oval.



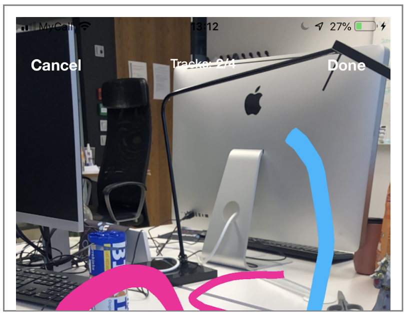
3D



Audio Only



2D



3D AR

12. **Por que você considera esta a pior versão?**

13. **Você encontrou alguma dificuldade realizando as tarefas?**

14. **Se você tiver algum comentário adicional, escreva-o aqui:**

Powered by Google Forms