Musical Brush: Exploring Creativity Through an AR-Based Tool for Sketching Music and Drawings

Rafael Valer(✉), Rodrigo Schramm, and Luciana Nedel

Federal University of Rio Grande do Sul, Porto Alegre, Brazil
{rvaler,nedel}@inf.ufrgs.br, rschramm@ufrgs.br

Abstract. The economic growth and social transformation in the 21st century are hardly based on creativity. To help with the development of this skill, the concept of Creativity Support Tools (CST) was proposed. In this paper, we introduce *Musical Brush* (MB), an artistic mobile application whose main focus is to allow novices to improvise music while creating drawings. We investigated different types of interactions and audiovisual feedbacks in the context of a mobile application that combines music with drawings in a natural way, measuring their impact on creativity support. In this study, we tested different user interactions with real-time sound generation, including 2D drawings, three-dimensional device movements, and visual representations on Augmented Reality (AR). A user study was conducted to explore the support for creativity of each setup. Results showed the suitability of the association of Musical Brush with augmented reality for creating sounds and drawings as a tool that supports the exploration and expressiveness.

Keywords: Augmented reality · Creativity support tools · Mobile application · Music · Drawing

1 Introduction

Digital tools, nowadays, play a crucial role in the most creative practices of our daily life. From young children playing on smartphones to create simple drawings to professional design artists, who depend on advanced graphical interfaces to accomplish their creative works. This growing link between digital instruments and creativity culminated in the emergence of a new subfield of Human-Computer Interaction (HCI), known as Creativity Support Tools (CST) [21].

More specifically, the research on CSTs focuses on the development of interfaces that aim not just the productivity of users but also the enhancement of their innovative potential, with the primary goal to support users on being more creative more often [20]. Among the interests in the study of CSTs, we can highlight the awareness of the benefits that these topics can provide on a global scale [8]. Works like [5,15] also point the importance of creativity on economic growth and social transformation.

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In this paper, we introduce *Musical Brush* (MB), an artistic application that allows novices to improvise music while creating drawings in AR. The main idea is to provide people in general with a highly expressive artistic tool that takes advantage of rich stimuli given by immersive environments. With the introduction of 3D drawings, we explore this new way to interact in the field of drawing-based tools. Furthermore, since we are particularly interested in exploring how the different application features may enhance creativity, we propose a practical user study where we explore the impact that the application‘s distinct features potentially have on the creativity of individuals.

We identify the central contributions of our project as the design and development of a novel immersive drawing-based musical application, along with the evaluation of the tool's main features regarding the enhancement of creativity. While we are aware that the achieved results are particular to our tool, we argue that many of the design choices could easily be extended to other digital tools that combine music and drawing. Moreover, we provide the overall creativity-related application scores, thus encouraging comparison with future works.

2 Related Workd

Since early works, a large number of different interactions and technologies were explored on the conception of new musical interfaces [12,17]. The use of gestural input parameters to control music in real-time is one of the explored approaches [23]. An early example work is the *Iamascope* [4]. The instrument constantly captures the scene image through a camera and uses the input to control and display graphics and sound in real-time. By applying image processing to the input image, users' body movements also directly control the sound and visual outputs. Similarly, in *3DinMotion* [18], real-time motion data from one or more subjects is used to create audiovisual pieces. By tracking the position of hands, it is possible to draw temporary traces in the 3D space.

Many are the possibilities when it comes to techniques and tools used in musical interfaces. One in particular is combining drawings and music. Drawing-based musical tools generally present highly visual elements and thus benefit from the degree of expressiveness that drawing representations offer. *The UPIC System* [11] presents a very early work in this direction. Composed by a drawing board and a pen, the system generates sounds according to the created sketches. On *Hyperscore* [3] the musical performance is composed of a set of several fragments that can be created and edited through drawing in the computer application, characteristics of the strokes such as color represent the timbre of the sound that is being produced. In *MicroJam* [14], users improvise short performances incrementally by creating drawings that represent sounds in a smartphone screen.

Still, most of the research on drawing-based musical interfaces focuses only on 2D interactions. Regarding this issue, immersive technologies have been explored to bring more freedom and expressiveness for musical tools [13]. Due to the capability of creating scenarios not feasible in the real world, new experiences not possible through traditional instruments can be created. Different immersive approaches have been explored for music composition. In Reactable [9], AR is used through physical markers on top of a table, displaying virtual contents and producing sounds based on interactions with the tangibles. Differently, *Virtual Air Guitar* [10] offers a VR guitar that resembles the real instrument through a CAVE-like room.

Different from the above tools, MB was developed as a portable AR experience for mobile devices, lacking any overhead needed for setting up environments, preparing head-mounted displays, or any other external device beforehand for its use. The application itself differs from other tools in several characteristics regarding music and interface. Finally, to produce a fair investigation about its potential capacity on supporting the creativity of individuals, we decided to compare the tool with different variation sets of its features.

3 Design Rational

A list of twelve principles that aim guidance in the development of new CSTs is proposed in [22], they prioritize strong support in hypothesis formation, speedier evaluation of alternatives, improved understanding through visualization, and better dissemination of results. Among the principles, we see relevance in the following: *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, and *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 [24]. Among the crucial characteristics for the design of real-time controllers listed in [6], we highlight: *"The human takes control of the situation. The computer is reactive"*; *"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 learnt until the actions become automatic"*; and *"Further practice develops increased control intimacy"*;.

Concerning the use of immersive technologies for musical purposes, [19] brings attempts to guide the conception of Virtual Reality (VR) interfaces. Despite focusing exclusively on VR musical instruments, some of the principles can also be addressed in an AR context: *P1) Reduce latency*, concerns the importance of having smooth interactions and highlights that the gap between different feedbacks should be minimized; *P2) Make Use of Existing Skills*, despite providing new experiences not possible in a real-world context, the use of interactions based on real actions can be interesting in the understanding of the tool; and *P3) Consider Both Natural and 'Magical' Interactions*, this principle highlights the importance of having actions that do not respect the real-world constraints and may cause a positive impact on users.

4 Implementation

MB is currently an iOS artistic application, and allows novices to improvise music while creating drawings in AR. The application essential operation consists of mapping different user interactions into sounds and drawings. In a similar concept to a Theremin, the generation of sound and drawings are controlled by 3D movements. When moving the smartphone device and/or performing drag gestures on the screen, the application creates a virtual 3D trace along the path traveled. The drawing strokes will permanently represent the performance melody structure. Both sound and visual outputs are shaped and controlled by several pre-defined interactions.

The app is written in the Swift language and implemented using ARKit. By continuously reading the video frames captured by the device's camera, the SDK detects and extracts feature points that are used for detecting planes and thus, place and anchor contents into the scene. The virtual objects represented as strokes in MB are created using the Metal API, which enables 3D graphics rendering in very high performance.

Fig. 1. Examples of performances composed with Musical Brush.

The main screen consists of two major components (see Fig. 1). The first and more important is the scene image, which is updated in real-time by the phone camera. This layer is also responsible for presenting the virtual drawings during a composition. To create the colored strokes, we continuously collect the position of the device at 60 fps, after that we create a tiny cylinder connecting the current and the last saved positions, thus creating a continuous stroke. The second component is the reproduction control segment, which lays at the bottom of the screen and is responsible for manipulating the performance execution.

4.1 Feature Extraction

To extract features from user input interactions, we are making use of several sensors present in a modern smartphone such as accelerometer, camera, and gyroscope to trigger and control both sound and visual outputs. This design, named *Direct Acquisition* [25], is defined by using one or more sensors to monitor the performer's actions in an independent way. So far, the elements being tracked are related to the device motion, acceleration, and position in a 3D space, as well as the recognition of touch and pressure gestures.

4.2 Mapping

The main concept behind the application is the combination of two distinct art forms: music, and drawing. To achieve this, we explored two distinct feedbacks in our application. The first is the audio, which consists of the real-time generation of sounds. Secondly, we have the visual feedback, which is represented by virtual colored traces, as shown in Fig. 1. Both sound and visual outputs are controlled and shaped based on user interactions and device motion. In this context, the visual strokes act as a way to represent the performance structure.

Several techniques have been considered to achieve our current sound mapping design. By aiming an interface that can be used by people with different degrees of musical experience, we focused on implementing a more naive direct sound mapping approach [27]. In general, simplistic *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 [6]. For this reason, the tradeoff between simplicity and engagement must be taken into account when designing a mapping strategy. Based on the features extracted from the sensors, the audiovisual characteristics controlled are as follows:

- **Sound/Stroke Generation:** Touching the screen activates the sound and drawing generation.
- **Pitch Control:** The vertical axis controls the sound frequency. The design follows the idea that people relate changes in the vertical axis with variations at the sound frequency [16].
- **Amplitude Control:** The force applied on touch gestures controls the sound amplitude and the thickness of the strokes. The design was based on the guideline that the output sound amplitude should be proportional to the amount of energy from input gestures [7].
- **Timbre Control:** The musical timbre is selected from a list of four pre-fixed waveforms, each responsible for coloring the stroke with a different color.
- **Delay Effect:** the activation of the delay effect is done by moving the phone abruptly. This design was based on the idea that *"there should be some sort of correspondence between the "size" of a control gesture and the acoustic result"* on musical instruments [26]. The effect visual representation causes the virtual strokes to vibrate along the time.

4.3 Sound Synthesis

MB makes use of a *Pure Data* (PD) based engine which allows the mapping of input parameters to a wide range of audio synthesis techniques. Through using Libpd as an embeddable library tool, it is possible to use the audio engine in mobile phone applications. A great benefit of exploring this engine is the high degree of flexibility to the sound generation module, providing an easy and fast way to further extensions of the proposed tool. Aiming to have a better-controlled testing environment, we have developed four different sound timbres using additive synthesis designed with oscillators based on sine, triangular, sawtooth, and square waveforms. The features are extracted in real-time and forwarded to the PD module. There, oscillators create and shape sounds based on the inputs.

4.4 Composition

The composition mechanism in MB is based on an incremental process where the artist creates new tracks (maximum of 6) that together will compose a performance. All the tracks have a duration length of 8 seconds and execute at the same time. The tracks are represented with virtual colored strokes (see Fig. 1), and its path follows the device movement during the composition. After creating a track, users can move the phone around and see the drawings from different perspectives. It is important to note that when played, all the distinct tracks start to be reproduced concurrently. Besides that, while composing a new track, the performer also perceives the audio and visual progress of the other already existent tracks, allowing a better understanding of the music arrangement. A demonstration video of MB is available online.[1]

5 Evaluation

To explore the effectiveness of our prototype concerning the support of creative characteristics, we propose a targeted user study. More specifically, we are interested in the investigation of three main topics: (1) *Is the design of MB successful in supporting creativity?* (2) *What aspects of creativity are impacted most?* (3) *What are the key features that impact substantially on this support?*

Measuring creativity is not trivial since the concept is ill-defined, with its measurement being approached in distinct ways by the community [1]. However, independently of the creativity definition, the Creativity Support Index (CSI) measurement tool [2], a psychometric survey specially designed to measure the capacity of CSTs on supporting individuals engaged on creative works, brings the evaluation of attributes that indirectly express fundamental qualities inherent to the majority of the creative processes, they are: *Results Worth Effort* (RWE), *Exploration*, *Collaboration*, *Immersion*, *Expressiveness*, and *Enjoyment*. In our context, creativity is quantified by the CSI scores measured during the user's interaction with MB when improvising new musical pieces.

[1] https://vimeo.com/313557959.

5.1 Compared Versions

In our user study, we compare four different versions of MB (AR, Sound Only (SO), 3D, and 2D) to measure how the different types of interactions and visualizations affect creativity. The three first modes present the same interaction system, where both touch gestures and device motion effects can be used to draw and generate sounds. The main difference is that the AR version presents the user with the camera image as background scene, and the virtual strokes are positioned on the real environment. The 3D version immerses the user in a "virtual" environment, where an infinite checkered floor replaces the camera image. Finally, the SO, does not present any drawing to users, generating only sound as output.

Unlike the above-mentioned versions, the 2D version does not use the motion of the device for the output, being the music composition exclusively affected by touch gestures on the device screen. In this case, the pitch is still controlled by the vertical axis position of the touches, and drawings can be created by sliding the finger over the screen. Figure 2 exemplifies the different compared versions.

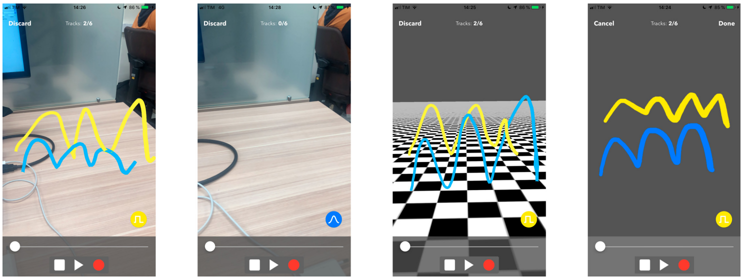

Fig. 2. Screenshots of the four compared versions, from left to right: AR, SO, 3D, and 2D.

5.2 Questionnaires

The questionnaires applied in this study are summarized here. The *Intake Questionnaire* (Q1) collects the participants' demographic information and previous experience regarding technology and music. The *CSI Questionnaire* (Q2) asks specific questions regarding the impact of the tool on creativity. Since our application does not offer collaboration, this attribute was not discussed within this work. The *Feedback Questionnaire* (Q3) consists of subjective questions with the objective to explore the participants' points of view on how the different interaction and visualization versions affected the creative process.

5.3 Protocol

The experiment consisted of a user study conducted with a total of 26 subjects. Since the experiment required users to move while performing, 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. The order of versions to be tested was different for each participant to prevent results to be biased. Each session lasted around 45 min, and was subdivided into four stages.

The ***Introduction*** stage began with an exaplanation of the study objective. Then, after accepting the terms and conditions of the study, Q1 was applied. In the ***Learning*** stage, we explained the features and general tool operation. Volunteers were encouraged to explore the tool and ask questions. In the ***Performing*** stage, participants were asked to create a performance for each different version. The content of the performance was free, and no limit for time was applied. After each session, participants were asked to answer to Q2. Lastly, in the ***Feedback*** stage, the participants were asked to reply to Q3, additionally expressing their thoughts about the full experience.

6 Results

The data from the questionnaires were analyzed by calculating the average (μ) and standard deviations (σ) and are reported here as ($\mu \pm \sigma$). After applying a Shapiro-Wilks test for normality, we observed that our samples deviate from a normal distribution. Consequently, we used the non-parametric Kruskal-Wallis test to identify significant differences between the four groups. Finally, a Dunn's Multiple Comparison post hoc test was applied when necessary for the dependent variables with different distributions. Significance level regarding the statistical tests is indicated in the figures with: (*) for $p < 0.05$.

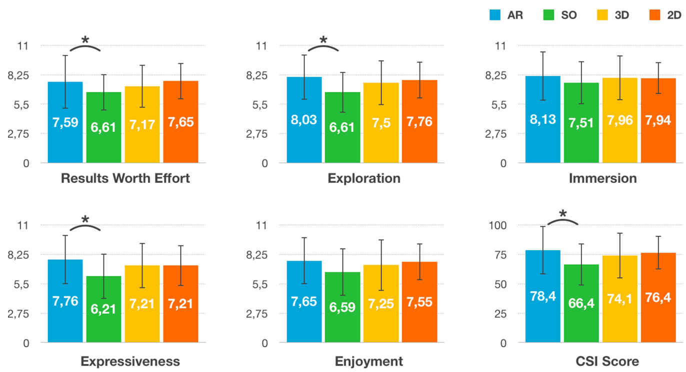

Fig. 3. Results from Q2. Significant differences were found regarding *RWE*, *Exploration*, *Expressiveness*, and the *CSI Score* between the AR and SO.

6.1 Population

The data from Q1 provides us with the necessary demographic information from the participants of the experiment. Among the 26 subjects, the age ranged from 18 to 28 (22.61 ± 2.60). While most of the subjects had at least some previous experience in musical practice (only 38.5% never practiced any instrument before), most of them never had any previous experience with mobile apps for musical creation (69.2%). Regarding AR, only 19.2% had used more than one app that explored this technology on mobile devices.

6.2 Resulting Data

Figure 3 brings the results obtained from Q2. The values of the first five creativity-related attributes (*RWE, Exploration, Immersion, Expressiveness*, and *Enjoyment*) range from 1 to 10 and are the basis for the CSI score calculation, which results in a score that ranges from 0 to 100. As we can notice, the AR version presented higher results in all attributes except for *RWE*. Two very high scores include the sensation of *Immersion* and *Exploration*. Among the results, *RWE*, *Exploration*, *Expressiveness*, and the *CSI Score* were significantly different ($p < 0.05$) among the AR and SO versions. The CSI results match the feedback given by users on Q3, where 57.7% of the participants elected the AR as the preferred version, against only 3.8% for the SO mode.

Table 1. Summary of collected usage logs for each of the four compared versions. Bold values indicate the highest average value.

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
Disc. Tracks	**1.15** $\pm$ 2.0	0.80 $\pm$ 1.2	0.5 $\pm$ 0.9	0.84 $\pm$ 1.4
H. Distance (m)	5.34 $\pm$ 3.6	4.35 $\pm$ 3.5	**6.23** $\pm$ 4.8	–
V. Distance (m)	4.31 $\pm$ 3.3	3.99 $\pm$ 2.6	**4.32** $\pm$ 3.4	–

Data from user compositions is summarized in Table 1, it includes the time spent in seconds during the task, the number of created and discarded tracks, and total horizontal and vertical device motion distances. Although not finding a significant difference among the conditions, the analysis of this data can reinforce some of our insights from the results. Characteristics such as the performance duration collaborate to the perception of a more enjoyable experience while the number of used and discarded tracks on the performance can be seen as a process of exploring different alternatives.

6.3 Discussion

In general, MB presented high scores for all the individual creativity-related attributes measured by the CSI (see Fig. 3). As final score, in a range from 0 to 100, the tool scored 78.4. The highest scores for individual attributes were 'Immersion' and 'Exploration', presenting scores of 8.13 and 8.03 in a range from 0 to 10, respectively. In the final pair-wise comparison among all the CSI measured attributes, 'Exploration' was considered the most important characteristic, with 28% of the answers relating this as the most essential aspect of the tool.

- 2D vs. 3D Interactions - Surprisingly, the 3D version results were not significantly different from the 2D version. When asked to report the negative points of the 3D version over the 2D, users mentioned difficulties in controlling the tool when performing: *"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 the 3D version users highlighted how the third dimension can increase the possibilities of exploration and expressiveness: *"greater space to be creative"*, (P1); and *"you have more freedom and available options to create"*, (P14).

Results from Fig. 3 evidence how the 2D version provides a greater user satisfaction when analyzing the *RWE* aspect. This outcome may be connected to the fact that, differently from all other compared versions, participants were allowed to stay still while performing, once that all interactions were related to touch gestures on the device screen. This lower physical demand may be noted in some comments concerning the 2D version advantages: *"Everything is at one place, no need to move around"*, and (P2); *"I could use while sitting, without much effort..."*, (P10). This ease of use due to reduced operation space can also be seen as an aspect that impacts exploration of ideas: *"with the limited environment it is easily visible the possibilities"*, (P9). Negative comments include being less fun: *"Less playful and interesting experience"*, (P11); and visual pollution due to the overlapping of strokes: *"Limited space for insertion of new points. On longer tracks, dots may overlap and difficult visualization"*, (P6).

- Sound vs. Visual Feedback - When exploring how the visual feedback impacted users' creativity, we were explicitly interested in comparing the AR and SO versions. The results show a significant difference between these two versions concerning *RWE*, *Exploration*, *Expressiveness*, and the *CSI Score* (see Fig. 3). The session length was longer on the AR version if compared to the SO, and also presented greater exploration in the number of tracks used (see Table 1). Furthermore, regarding the advantages in the presence of visual strokes the participants mentioned distinct benefits, including:

– *Exploration* - *"It's more clear on what I am doing, easier to experiment"*, (P3); and *"...they facilitate the creation of sounds, helping to understand if I want to put the sounds close or not"*, (P14);
– *Immersion* - *"It makes me focus on more than just one sense"*, (P11); and *"...give the feeling that the sounds produced are touchable"*, (P12);

– *Expressiveness* - *"It becomes another art form, in addition to the music it makes"*, (P2); and *"It helped me to come up with more ideas. I was wondering what would be the sound if I drew a happy face, or a star..."*, (P17).

On the other hand, a few users reported how the visual strokes disrupted their focus while composing: *"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).

- Real vs Virtual Environment - The comparison between AR and 3D versions was performed within a more exploratory approach, and we acknowledge that comparing a real environment against a virtual one with no visual appeal is unfair. However, although not presenting any appealing objects in its environment, results show that participants moved more in the 3D version. We believe that this may be related to the exploration of a new environment not previously known. On the other hand, the AR version presented higher scores on every CSI attribute (see Fig. 3). User feedback concerning the positive points of interacting with the real environment includes the ability to interact and draw on real objects, and the enhanced sensation of immersion due to the self-perception of being among the virtual strokes: *"It's fun to move around the room and create things everywhere"*, (P5); and *"The real world brings inspiration to try things you wouldn't do normally, it's fun to play with your surroundings"*, (P25).

7 Conclusion and Future Works

In this paper, we presented *Musical Brush*, a drawing-based musical application that allows novices to improvise music while drawing. We conducted a comparative study exploring different features of an interface designed for artistic purposes. More specifically, we were interested in exploring how the tool different features could support distinct attributes related to creativity. Among the key findings, we discovered that the visual drawings are crucial for a significant enhancement of creative-related aspects. By providing visual feedback to the user actions, the drawings were responsible for improving the expressiveness and exploratory capacity. Furthermore, the visual feedback was also highlighted for increasing the immersion of performers due to its surrounding 3D drawings.

Although not presenting significant statistical differences regarding creativity support aspects, the comparison among 2D and 3D versions produced interesting results. It is clear that all types of interactions can be somehow useful for applications that integrate music with drawings. However, the choice of this specific interaction is, in fact, a tradeoff between controllability and expressiveness. Feedback indicated that the 2D was preferred for rapid and efficient control of application parameters, while 3D was preferred for freedom, and exploration of different possibilities.

A limitation of the proposed prototype application, however, was the difficulty of creating some concrete and more pleasant results due to the still non-complex sound generation system. Regarding future steps, we aim to focus on three distinct fronts. Firstly, we would like to explore more AR technology and measure aspects regarding creativity while interacting with outdoor environments. Secondly, we would like to incorporate and evaluate the collaborative aspect. Lastly, we would like to perform further investigations regarding the use of 3D interactions to control real-time audiovisual content, as well as explore more complex sound mappings.

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