



Exploring the Theoretical Landscape of BehCreative: Artistic and Therapeutic Possibilities of an Extended Digital Musical Instrument

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Abstract. In the digital age, technology has become ubiquitous in various fields of knowledge, functioning as an extension of the human body – akin to a technological body. Consequently, it acquires ecological validity in our daily lives and offers a path for developing studies rooted in Embodied Cognition. This idea is illustrated by BehCreative, an Extended Digital Musical Instrument (EDMI) introduced and presented in this article. The article delineates the design, mapping and architecture of BehCreative from both musical and cognitive standpoints. Moreover, it explores how these instruments bridge the divide between traditional musical interfaces and immersive technologies, thereby redefining the limits of artistic expression and therapeutic interventions. The article highlights that BehCreative, as a hybrid instrument, holds the potential to facilitate therapeutic recovery and serve as an artistic tool for expressive purposes. Given its hybrid nature, BehCreative presents diverse possibilities for exploring users' behavioral learning, as evidenced by the results of a mentioned exploratory study. Consequently, it substantiates the hypothesis of being an instrument that warrants examination from an interdisciplinary perspective.

Keywords: Music Therapy · Embodied Cognition · Artistic Installations · Creative Empowerment · EDM I

1 Introduction

Recent research in interactive therapies, grounded in technological advancements, has highlighted the utilization of immersive experiences, including Virtual Reality (VR) [1–3]. Some of these applications are connected to the utilization of interactive musical systems and Digital Musical Instruments (DMIs) [4]. One of the reasons to consider these studies stems from the burgeoning literature and practical implementations focused on the design of DMIs in therapeutic contexts [5]. The capacity to engage patients through

musical processes controlled by gestures holds the potential to foster constructive effects on their involvement in the therapeutic process.

This article aims to build upon prior work [4] by delving into its theoretical dimension, thereby establishing the theoretical framework for deploying Extended Digital Musical Instruments (EDMI) within music therapy and rehabilitation frameworks. Consequently, the article delves into theories of embodied cognition that bridge diverse domains encompassing technology, music therapy, art, and music. In doing so, it develops a comprehensive exploration of the interconnected relationships among these domains, presenting a novel perspective on the therapeutic and rehabilitative potential of EDMIs within the music technology context. First, we define convergent aspects of DMIs [6] as prospective elements in the musical and therapeutic field. One of the most relevant points is the great potential for interactive music and immersive environments for studying human cognition and its relation to interactive musical models [7]. This discourse stems from concepts rooted in DMIs and the application of mixed reality as a framework for designing immersive therapeutic environments [8].

Further, we discuss the dialogue between our approach and the Ecological Perspective [9] as well as the paradigm of Embodied Cognition. Embodied Learning surfaces as a significant factor engaged in dialogue with the concepts of Aesthetic Resonance as posited by Swingler [10], Ellis [11], and Aesthetic Resonance [12, 13]. Subsequently, we consolidate these viewpoints to introduce the notion of EDMIs and discuss a methodological approach for harnessing such extended digital instruments. This framework paves the way for developing therapeutic methods and the design of experiments within this domain.

Moreover, we also introduce the implementation of an EDMIs named BehCreative. This EDMIs combines virtual and physical elements, creating a hybrid environment where the boundaries between the real and virtual worlds become blurred. Beyond that, BehCreative aligns with the principles of embodied cognition, motor learning, and therapeutic modalities. In the concluding sections of the article, we contemplate the implications of constructing therapeutic processes rooted in immersive installations.

2 Theoretical Background

This session presents the main concepts supporting the approach presented here. We begin the discussion with DMIs [6]. Next, we delve into the concepts related to Mixed Reality, followed by relevant aspects of Gibson's ecological theory [9], Embodied Learning, and Musical Cognition. These various aspects are interconnected to define the notion of EDMIs, a key concept that supports our research methodology and the design of an experimental setup.

2.1 Digital Musical Instruments (DMI)

Miranda & Wanderley [6] defined that DMIs employ sensing technology, computer hardware, and software to craft novel musical instruments, providing users and musicians with a diverse range of possibilities for interaction. Unlike traditional musical instruments, a DMI separates its sound production unit from the gestural control unit [6].

Consequently, any instrument or object linked to digital circuitry can generate sound as an output. DMIs exhibit four main categories: 1) alternate controllers, 2) augmented or hyper-instruments, 3) instrument-like controllers, and 4) acoustic instrument-inspired controllers [6].

2.2 Mixed Reality and the Extended Paradigm

Mixed Reality (MR) is defined as “the merging of the real environment and the virtual world” [14]. In an interactive mixed reality environment, the user experiences the space as a performer. This involves two interconnected situations: real actions (i.e., live actions performed by the user) and the processing of information, both connected in real and virtual environments [15]. The user’s experience in a mixed reality performance is balanced between the real and virtual, creating a more engaging interaction. Giannachi & Benford [16] describe a mixed reality performance as “... both their mixing of the real and virtual as well as their combination of live performance and interactivity” (p. 1).

The merging perspective of the real and virtual is essential for the research presented here, as we later define the notion of Extended DMIs and introduce our studied system, BehCreative. In a mixed reality environment, digital technologies seamlessly integrate with physical interfaces in the real world, enhancing the user’s musical experience. In our approach interaction is a crucial aspect of the user’s experience, engaging them from both real and virtual perspectives. This characteristic offers multiple points of view for the observer, as each user explores the performative space subjectively, influenced by temporal perspective, perceptual dynamics, kinetic possibilities of their body, and the type of performance, whether continuous or discontinuous. All these points make mixed reality a highly relevant perspective, as it involves the user’s performance within an immersive system that responds in real-time. BehCreative utilizes various types of sensory simulation - visual, sound, and proprioceptive - through mixed reality, allowing for exploration and study beyond the Virtual Reality (VR) perspective, thus intensifying the user’s experience.

2.3 Ecology of Perception and DMIs

We can infer that one of the foundations of DMIs is grounded in the idea of how technological tools provide body extensions to the user, simplifying certain situations while amplifying the results. This is why it is important to maintain a continuous dialogue with Embodied Cognition: we need to understand how humans interact with the technological environment and how it influences our actions, such as exploration, learning, and behavior. For example, considering some perspectives from Gibson’s theory of visual perception, particularly regarding artworks, he refers to artworks as ways of communication that do not contain signals to be sent to the subject, but rather direct information available to the observer, mediated by perception. As Dourish [17] summarizes:

“Gibson’s starting point was to consider visual perception not as a link between optics and neural activity, but as a point of contact between the creature and its environment, an environment in which the creature moves around and within which it acts” (p. 117).

Likewise, Nöe & O'Regan [18] expound upon visual perception to elucidate the Sensorimotor Contingency Theory (SCT). According to the authors, from the perspective of the visual sensorimotor approach (i.e. which performs sensory and motor functions),

“Vision is a capability not confined to the brain alone; it encompasses the entirety of the environmentally situated perceiver... The brain’s role in producing vision lies in enabling active exploration based on implicit awareness of sensorimotor contingencies” (p. 593).

The Sensorimotor Contingency Theory (SCT) says the role of movement is very important to explain visual perception and other sensorimotor contingencies. This idea aids in unraveling the dynamics within the performative space introduced in this paper. According to the ecological theory viewpoint [9], the relationship between the subject and its surrounding environment shapes human experience. Furthermore, Gibson’s theory can be applied to the realm of music and technology, where the experiences of musicians and music technologies undertake the relationship between the subjects and the surrounding technological environment.

Dialoguing with Gibson’s concept of affordance, we defined the notion of *Virtual Affordance* as the properties of the interactive virtual environment that suggest possible or available actions based on the user’s perception. In resonance with this idea, it is possible to allow for direct manipulation of Virtual Affordances, offering degrees of freedom to the user’s behavior within the performative space. These results in an exchange of information between the environment and the subject, in a cyclical process.

2.4 Art, Technology and Creative Empowerment

Our approach establishes a meaningful dialogue between Art and Technology, which holds significant importance in the clinical-therapeutic field [19]. The use of music technology as a tool for promoting prevention and treatment of psychological and physical pathologies and improving the quality of life of clients and music therapists is gaining recognition.

A significant concept related to our research is the concept of Aesthetic Resonance [12, 13] and the notion of Creative Empowerment [4]. Creative Empowerment is about empowering individuals to use technology to enhance their creativity and feel a sense of control and agency over the creative process. By providing tools and resources that allow users to express their creativity in new and innovative ways, designers can foster engagement, motivation, and satisfaction, particularly within a therapeutic process. It enables individuals to explore and develop their creative skills and talents in ways that were not previously possible.

Furthermore, interactive systems have demonstrated effectiveness in motor rehabilitation, accelerating motor recovery and facilitating the internal transfer of skills to daily life [20, 21]. In the rehabilitation field, self-expression and artistic creation play vital roles in involving and motivating clients. Our research main goal is to facilitate the performer’s self-expression, as achieving Creative Empowerment is a turning point in personal and physical recovery.

These concepts should be considered within the paradigm of embedded cognition, helping readers to understand the aesthetic perspective that stems from sensorimotor and perceptual experiences. The extended instrument, manipulated through the user's performance and sense of agency, involves both cognitive and physical aspects. Manipulation, in this case, is cognitive, incorporated but also physical: a physicality that gives pleasure, and that is co-determined by Creative Empowerment.

In summary, our approach seeks to create an immersive and empowering experience for users, combining the artistic and technological aspects in a manner that enhances therapeutic outcomes.

3 Extended Digital Musical Instrument (EDMI)

After discussing the main theoretical issues related to the study presented here, we can now define the central concept of our research: the notion of Extended Digital Musical Instrument (EDMI). This concept is exemplified by the system we created, BehCreative, which serves as an instance of an EDM I.

3.1 Defining the EDM I

As described in the theoretical framework, we bring back Gibson's Theory of Visual Perception [9] to outline the notion of EDM I, as previously defined by Partesotti [22]. Gibson argued in his theory that "[w]e must perceive in order to move, but we must also move in order to perceive." This concept implies a continuum between perception and action. To understand perception, we must start from the experience of the body in the surrounding environment. Our experience is bodily mediated, and guided by sensorimotor objectives. Perception and action are intrinsically linked, guided by mirror neurons (activated by observing a person performing an action) and canonical neurons (activated in the observation of objects) [23].

The concept of EDM I goes beyond the scope of Digital Musical Instruments (DMI). Unlike DMIs, which primarily focus on digital technology and interfaces, EDMIs initially embrace the concepts of environment, ecology and immersion. These instruments prioritize corporeality as a key element in interpreting reality and shaping the overall musical experience. By emphasizing the embodied interaction between the musician and the environment, EDMIs offer a new dimension of expressive possibilities and engagement.

BehCreative, our implementation of an EDM I, reflects these principles and concepts. It is an immersive environment where we developed our research methodology and completed an exploratory study [24]. The performer's interaction in this environment is distributed throughout the performative space and depends on the real-time connection between the machines. The performer receives an immersive and visual octophonic sound response, guiding their proprioception. BehCreative becomes an extension of the performer's own body, as the user herself/himself chooses when to stop using this 'virtual' instrument mixed with their body, activating points of rest. The tool extends our abilities [22] in a dimension where perception and cognition depend on the performer's interactions within the environment.

3.2 EDM I Adaptation and Extending Functionality

Mapping is utilized within BehCreative to define potential behaviors, granting users the freedom to interact and bring them to the forefront based on their preferences. An acoustic instrument, despite allowing to be played in different ways, will always remain faithful to its physical components (material, possible frequencies, and harmonics), as well as the exploration and feedback it offers. The EDM I is a unique musical instrument that is not predefined in its functionality. Unlike acoustic counterparts, the EDM I's capabilities depend on the user's behavior, making it a versatile and immersive tool for musical expression. It embraces the concept of being extended, immersive, and open to diverse ways of interaction through the user's body. This perspective highlights the significance of embodied learning, where the user's process of engaging with the instrument involves self-reflection and body awareness, leading to Creative Empowerment. By actively involving the user's body in the musical experience, the EDM I encourages a deeper connection and understanding of the instrument's potential for creative expression.

In summary, the virtual EDM I instrument offers a dynamic and immersive musical experience that is not constrained by predefined rules. Through embodied learning and its extended and immersive features, it promotes Creative Empowerment and opens the door to intelligent and adaptive musical systems.

4 Implementation of BehCreative

After discussing the concept of EDM I, we now delve into the implementation of our system, BehCreative, focusing on three key aspects: designing, mapping, and architecture. This prototype (Fig. 1) is based on the investigation of the correspondence between color and music, such as synesthesia [22, 25].

4.1 Design of BehCreative

In the design of EDM Is, a crucial aspect is the mapping. It is a critical element for the tool's usability and effectiveness [26]. As described by [27], mapping refers to the correspondence between control parameters derived from the performer's actions or gestures and the parameters of sound synthesis. This term defines the choice of inputs within an interactive music system and during a performance, which are then transformed into expressive outputs or feedback for the performer. The selection of inputs involves analyzing and observing the collected data, which depends on the objective of the EDM I. The mapping's characteristics vary from one instrument to another; some DMIs may have intuitive mappings, correlating physical and musical gestures, while others may not be as clear to the user. The mapping holds significance as it represents the architecture of the entire technology and shapes the purpose of the interactive multimodal system. Figures 2 and 3 illustrate the distinctions between the mapping of a DMI and of an EDM I, such as BehCreative. Figure 3 depicts how BehCreative expands Miranda and Wanderley's notion of processing [6].

In fact, in BehCreative, the user becomes the performer and input into a cycle of co-determination between performance and the performative space. This input is derived

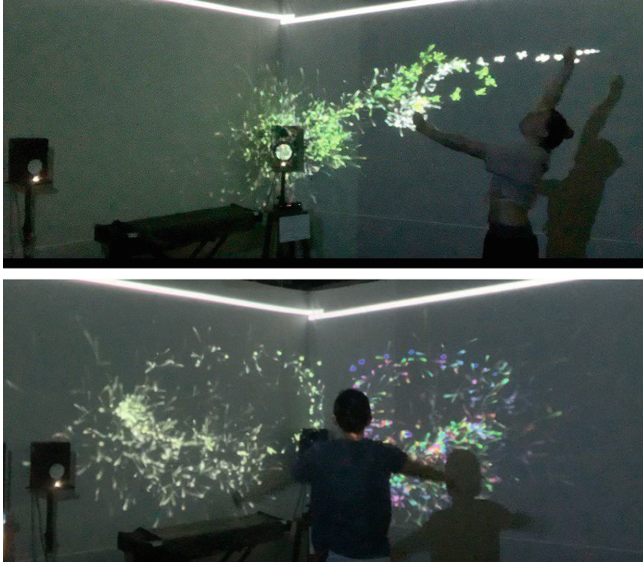


Fig. 1. Two users during an experiment with BehCreative.

from the user's own body movements and gestures in the general performative space. The data received by the MOCAP (Kinect 2) are then processed, and the body data are transformed into visual feedback (Processing Programming Environment) displayed on windows, which are projected on the three canvases around the user. Simultaneously, these data are sent via OSC to the software that interprets them to produce the sound output, including sonification and Virtual Affordances from the octophonic system (Pure Data in MAC IOS). Since the body in space is fundamental for an Extended DMI, the consideration of the user's interaction with the space in which it is immersed expands the notion of DMI proposed by Miranda & Wanderley (2006) in the input and processing of data.

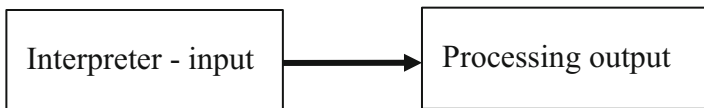


Fig. 2. Basic Diagram of a DMI proposed by Miranda and Wanderley, 2006.

4.2 Mapping of BehCreative

The mapping for an EDMI, therefore, encompasses both technical and theoretical aspects that are essential to consider in 'hybrid' applications, whether they are artistic or therapeutic.

From a technical standpoint, in BehCreative, the processing occurs through a network using the OSC protocol, involving the analysis of body tracking data obtained

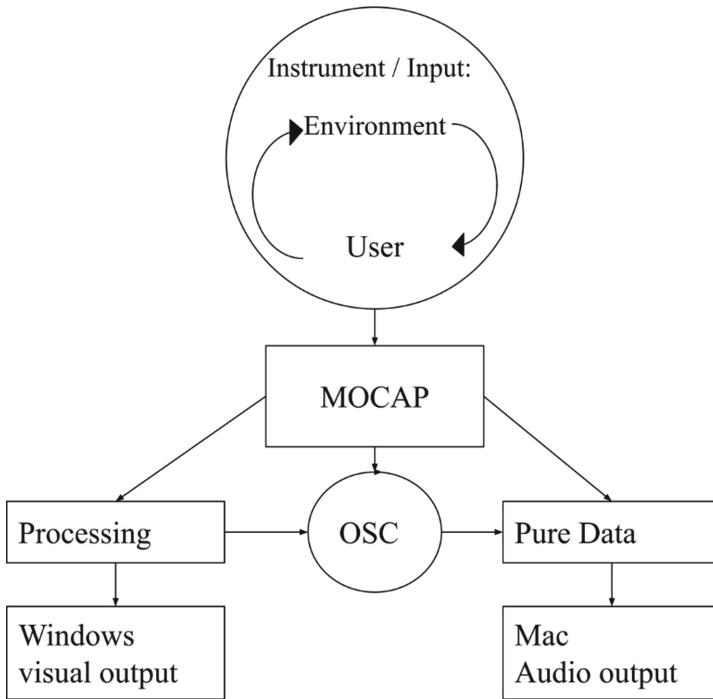


Fig. 3. Mapping of an EDM.

from Kinect 2. This network serves two functions: it receives, processes, and shares the input data, and also acts as a general audiovisual controller. On one side, there is the Processing Programming Environment generating visuals, and subsequently, Pure Data (PD) receives the encoded movement signal, already translated into Virtual Affordances. The resulting sound is then diffused through an octophonic system, immersing the user in the BehCreative installation. This immersion is a fundamental condition of an EDM. Through joint exploration, which leads to the proprioceptive experience of the user, the interaction with BehCreative takes place.

4.3 BehCreative Interactive Behavior

As described before, BehCreative is structured in layers, with particular attention given to sound feedback, as it functions as an extended musical instrument. Consequently, consonance and dissonance feedbacks are implemented, reacting according to the user's movements in the environment, along with various Virtual Affordances. Hence, in BehCreative, there are interactive rules that are activated through the co-determination process between the user and the environment. These interactive rules include:

Fluidity: The quantity of movement established a priori within a certain range. More balance in fluidity leads to more balanced sonification, i.e., consonance by the octophonic system. Thus, it is related to jerk.

Jerk: The variation of acceleration that influences the sense of fluidity. This variable is responsible for implementing consonance and dissonance feedback. If the subject activates the jerk, the feedback is consonant, leading to a state of fluidity. Otherwise, the auditory feedback will be dissonant, while the visual feedback is black and white.

Virtual Affordances: This represents sensorimotor feedback, which is given by the sense of proprioception - i.e., awareness of the body moving within the environment. Precise movements trigger specific sound and visual feedback, which the subject discovers through exploration and learns to use by creating their own Sensorimotor Maps.

Tunnel: This variable represents the predetermined range for positive outcomes and reflects the user's ability.

Momentum: It controls sound/silence and is linked to the number of particles shown in the visual feedback.

PoR (Point of Rest): The Point of Rest is determined by the user's movements. When the user stops or goes down on the ground, the system also stops.

5 Applications of BehCreative

5.1 BehCreative Applied in Artistic Production

It emerges that in BehCreative, the user becomes a performer, composer, and artist, producing their own unrestricted feedback. Art installations act as bridges between reality and its possible interpretations. From this perspective, BehCreative represents an interesting possibility to experience and understand the relationship between the body, technology, and art, as well as the direct communication skills that this EDMi possesses and offers.

5.2 BehCreative in Therapeutic Applications

Considering this new embodied approach, we believe it should always be applied, especially when considering DMIs for therapeutic and ludic applications through mixed reality systems.

VR can be used, among other things, to develop therapeutic and ludic applications. This is the case of Rehabilitation Gaming System (RGS), a VR based system. RGS for functional recovery of the nervous system lesions using a non-invasive approach has been developed by [28]. The key lies in providing users with a sense of control and agency over the instrument. A crucial difference between BehCreative - as Mixed Reality environment - and VR-based RGS is that they can deceive the brain for performative purposes, making the patient believe they have successfully performed a movement when the movement is limited. This stimulates the patient to improve their performance [22]. We have run the BehCreative protocol for the experiments, which included the study of the subjects' functional magnetic resonance imaging (fMRI) exam. The results obtained so far show activation of the regions connected with the rewarding system [24].

On the other hand, BehCreative takes a different perspective from RGS-based concepts, allowing the user to progress in a psychological-emotional process or motor rehabilitation through the pleasure triggered by free audiovisual feedback, experienced throughout the entire body in motion. This feedback is immediate, controlled, and pleasant. Unlike in VR, in a mixed reality system as BehCreative, the pleasure here bodily, satisfying the user because it is not just a response within a virtual game, but the body itself that is involved, providing immediate control over the feedback (i.e., the artistic production in this case). If users do not like the feedback produced, they can simply move differently to explore new paths and create their own trajectories and Virtual Affordances [22].

5.3 BehCreative in Music Therapy

Despite the development of MOCAP technologies in the artistic field, the presence of EDMIs in music therapy is currently quite limited, with rare exceptions like MotionComposer [20]. Most EDMIs are primarily used in workshops or for research and are not systematically integrated into therapeutic sessions, partly due to their expensive cost. However, as we have explored in this article, the potential that this type of music technology offers to caregivers and users is vast, especially with the ability to customize the mapping to meet the client's specific needs.

For example, in BehCreative the user remains the central figure, paying attention to their movements and how they interact with the visual and sound variables. These interactions generate consonant or dissonant feedback, as well as black and white or colored outputs. BehCreative promotes bodily awareness while providing a valuable tool for investigating the behavioral learning of the user through quantitative and qualitative data recording. It captures data such as the user's jerk, sound, and visual feedback (including Virtual Affordances), and even affective variables using the Affective Sliders questionnaire [29]. The therapist can then analyze the level of user involvement based on these data if needed, as described in [30].

6 Discussion

This article underscores the potential of a research approach in the realm of musical interactivity and its related technologies, particularly in immersive therapies utilizing music and sounds for interaction. We argue that such technologies, which enhance musical control through gestures, improve engagement in the therapeutic process. The article begins by providing a comprehensive definition of Extended Digital Musical Instrument (EDMI) and then introduces the implementation of BehCreative. This interdisciplinary approach combines ecological psychology and mixed reality concepts with musical technology, primarily DMI.

The creation and implementation of BehCreative involved sound and visual environments and computational tools like Processing Programming, Pure Data or Max MXP. The experimental design anchored its methodology in embodied cognition, motor learning, and creative empowerment. Furthermore, the production of sound stimuli drew from musical composition methods adapted from sonic design for interactive environments.

BehCreative represents the convergence of these diverse elements in both its conceptual framework and practical applications.

In the studies of musical cognition and its therapeutic applications, developing new methodologies is crucial to effectively address the complexity of the area. As the field continues to evolve, interdisciplinary dialogues and collaborations with other areas of knowledge, such as philosophy, psychology, neuroscience, and technology, become increasingly important. Engaging with these fields broadens our understanding of how music is processed, experienced, and utilized in therapeutic contexts - i.e. between neuroscience and music therapy [31].

Recently, Manzolli [32] introduced Ecological Methodologies such as presented here in two aspects: 1) a network of complex data available for creative exploration, and 2) data tracking and behavior analysis in an environment where interaction with various devices indicates how the environment affects actions and derives meaning from the interaction. We foresee the potential of such methodology in the Neuroscience of Music and its application in immersive technology for music therapy.

BehCreative has recently been installed at NICS's Laboratory. As mentioned earlier, our approach aims to foster cooperation and creativity through interaction with an environment that becomes sensitive to human presence and engages in a dialogue with it [33].

Laboratories with installations such BehCreative, grounded in initiatives such as this, have tremendous potential to facilitate dialogues between various areas of knowledge within the musical field and beyond. This includes interactive music composition, musical performance with the support of new technologies, studies on music perception and musical cognition, and most importantly, applications in therapeutic domains. The concept of the Extended Digital Music Instrument (EDMI) expands beyond BehCreative's implementation and offers broad possibilities for interdisciplinary exploration.

BehCreative is an innovation resulting from interdisciplinary engagement, born from the collaboration of several research fields, including music cognition, neurotechnology, musicology, and music technology. It possesses both therapeutic and artistic applications. On one hand, it holds potential for use in rehabilitation therapy and music therapy [22]. On the other hand, it serves as an artistic installation with pedagogical potential, enabling learning about the relationship between colors and sounds, as well as the embodiment of musical concepts. As an extended instrument at a cognitive level and augmented at a mapping level, it fosters creativity in the user, empowering them to explore new creative dimensions.

7 Conclusion

In this paper, we introduce and elucidate BehCreative - an instance of our definition of an Extended Digital Music Instrument (EDMI). BehCreative a new hybrid music technology suited for both therapeutic and artistic contexts. We establish a distinction between Digital Musical Instruments (DMIs) and EDMIs. While DMIs utilize digital interfaces to amplify musicians' expressive capabilities, EDMIs seamlessly integrate gesture, sound interactions, and other sensory modalities to craft immersive and engaging musical experiences.

Our research and design process unveil that the system's behavior, aligned with the audiovisual responses of BehCreative, is intricately shaped by real-time user interactions within the installation environment. This user-initiated engagement and inherent self-organization present an innovative approach to designing artistic, therapeutic, and pedagogical musical technologies. In our pilot experiment [24] we observed neuronal activation in areas associated with the brain's reward system. The results suggest the tool's potential in stimulating neuroplasticity. Notably, even with a limited number of subjects, significant out-comes emerged.

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