Chapter 13
Extended Digital Musical Instruments to Empower Well-Being Through Creativity

Elena Partesotti

Abstract At this time of considerable technological development, interdisciplinarity assumes a key role in the advancement of research and the design of virtual reality and immersive environments. In this chapter, I will start by reporting some significant examples of technologies designed to generate new creative and therapeutic spaces that use the user's movements, such as *CARE HERE*, *e-mocomu* and *Sentire*, and I will then describe the design prototyping of *BehCreative*. At the basis of these technologies are a few common features, including a sense of control, a multimodal design, and sensor-free performative movement. I will also address music therapy and rehabilitation, empowerment and Creative Empowerment based on the embodied cognition paradigm—a concept already present in the research of other authors yet never studied in depth or connected with Extended Digital Musical Instruments (EDMIs).

Keywords Creative empowerment · BehCreative · Interaction · DMI · EDMI · Music therapy · Rehabilitation

13.1 Extended Digital Musical Instruments

From 1980 up to now, the use of interactive digital technologies has grown extensively in several fields; in addition, interdisciplinarity between scientific and humanistic subjects has increasingly proved beneficial. A dialogue has emerged from the need to develop "methodologies for designing systems of easier and more immediate use" in [1, 2]).

Over the years, this has led to the design of experimental technologies that are grounded in the interconnection between action and the subject's perception of it

"[...] the essence of technology is by no means anything technological" Heidegger, 1977.

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and are easy to use, even in the health field, such as in the area of rehabilitation and music therapy. When combined with the music sector, these technologies enable users without any pre-existing musical abilities and with physical challenges to play an instrument properly, producing a highly proficient, expressive and creative outcome. As a consequence, the use of technology itself continues to transform, enhancing and reprogramming traditional learning schemes by introducing new, subjective stimuli. This is possible through the use of motion capture (MOCAP) technology, which enables the sensorless body tracking of the user. This is the case with Extended Digital Musical Instruments (EDMI), which means that we use and control these DMI as artefacts "in order to extend our abilities" [3]. In other words EDMI are instruments that allows a distribute interaction within the space on a practical level, and—as property—promote a sense of agency and control on a cognitive one. In this way the user can create new way to cognise with such tools [4]. EDMI are thus extended in a cognitive, sensorimotor and perceptual level.

From this perspective, it appears that the creative and cognitive dimensions are interdependent, since MOCAP technologies promote immersive, performative environments in which the user creates and extends new connections, or new ways to pursue a goal through their movements. And it is precisely through these movements, presented in the context of an exploratory experience, that the user can gain full control over the technology, thus achieving *Creative Empowerment*.

With this term, I refer to the subject's mastery of technology, which—once achieved—facilitates the subject's creative self-expression [5].

Movements are regulated by the person's exploration of the environment through their ability to master sensorimotor contingencies—a form of control that depends on practice [6]. This proficiency can lead to the *flow* that is associated with the creative opportunities that such an experience can offer the user.

Moreover, everyone has equal opportunities for artistic creation and self-expression, as referenced in the psychology of empowerment, and this feature enables us to achieve goals through a collaborative relationship with a therapist, in which the therapist works together with the client rather than acting as an expert. I will describe these concepts in the following paragraphs.

In order to offer the user an EDMI that helps them achieve full creative expression and self-awareness, we need to empower these very users in EDMI design. The design of assistive technology is, in fact, paramount given that the effectiveness of treatment will depend on it. Participatory and co-design methods include different steps in the construction of a user-friendly technology, including users in the design process. These tools should provide users with a structure and scaffold for creativity and, more importantly, these processes should involve users with a diverse grade of disabilities in order to offer assistive technology that is effective yet inclusive [7].

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13.1.1 Music Therapy and the Mirroring Phase

Music is a medium for describing how to move, think and socialise [8], acting as a resource for the body that can be thought of as a technological prosthesis, or a material that extends the capabilities and actions of the body. In other words, "[…] music is an accomplice of body configuration. It is a technology of body building, a device that affords capacity, motivation, coordination, energy and endurance" [8]. As with musical instruments and technological systems, music itself must be understood for its non-verbal abilities, activation and imitation of the user (2000). As DeNora points out

> [m]usic's role as a resource for configuring emotional and embodied agency is not one that can be predetermined […] Music not only affects how people feel emotionally; it also affects the physical body by providing a ground for self-perception of the body, and by providing entrainment devices and prosthetic technologies for the body (2000).

Already considered a means for medical treatment and psychophysical well-being in primitive societies (2,000 BC), nowadays music is used as a therapeutic tool that brings psychophysiological and physical benefits to the individual and continues to be studied for its neurophysiological effects. Today, for example, we know that music influences the immune and neurohormonal systems [9], modulating, in particular, the function of the autonomic nervous system and metabolism [10] and increasing self-perceived well-being [11].

Music therapy has been officially recognised at different times in different cultures. In the United States, it only became official in 1998, when the American music therapy Association was formed. In Europe, however, the European music therapy Confederation was established in 1990. The discipline consists of the systematic application of music, directed by a professional in a therapeutic environment, with the goal of activating biological, psychological, intellectual, physiological, social and spiritual mechanisms through the proposed musical activities [12]. The music therapy approach includes different methodologies that professionals can apply, depending on their training, in sessions with clients.

Within the clinical improvisation of the Nordoff-Robbins methodology, for example, music therapy stimulates interaction on various levels. Indeed, one of the most important aspects in music therapy is the concept of innate musicality, taken from the Nordoff-Robbins methodology, which is taught mainly in the United States and applied through clinical improvisation. Also referred to as the *music child*, this concept conveys the idea that any person—regardless of their pathology—keeps their musical intelligence intact and is able to respond naturally and spontaneously to sound stimuli. In fact, the Nordoff-Robbins methodology emphasises the peculiarity of innate music, thus opening up the possibility of direct communication with the client [13]. Improvisation is a fundamental aspect that occupies a central part, as for the therapist, "the music improvised in sessions is an embodiment or expression of the client in any one moment" [14]. Indeed, during improvisation, emotional creativity emerges in the communicative musical act (2000) and in "rebuilding a new schema after the shattering of one's belief system […] and of rediscovery of the

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mind–body connection" [15]. Therefore, the term "clinical or creative improvisation" is applied as a technique, which represents "specific therapeutic meaning and purpose in an environment facilitating response and interaction" (APMT 1985).

This type of improvisation is free: it is a constant observation of the type of material that emerges between therapist and client, establishing a listening-response dialogue [14]. In Nordoff-Robbins, the therapeutic process involves a period of time consisting of distinct phases, which, as Lorenzo [16] reports, are usually divided into three steps:

1. *Reflection*. The therapist acts as a *mirror* to the client, reflecting their reactions and attitudes, ensuring the client feels listened to and accepted and helping them to achieve self-awareness.
2. *Identification*. In this phase, the client has already reached a certain level of awareness of their own attitudes and reactions.
3. *Contact*. This stage involves the consolidation of the client-therapist bond of trust, in which the subject accepts the therapist's interventions and aid, and positively advances in the therapeutic process.

Regarding the importance of the first phase, in which the music therapist acts as a *mirror* to reflect the client's musical behaviour, Trevarthen and Malloch [14] underline that this process enables clients to see a reflection of themselves to aid self-understanding.

This crucial aspect also connects music therapy with current body philosophy, in particular the *embodied simulation* model, a concept proposed by [17] and the specific phenomenal state called *intentional consonance* [18]. Intentional consonance or *attunement* generates a sort of familiarity with individuals and happens when we recognise others as being similar to ourselves, making non-linguistic interpersonal communication possible through our mirror mechanisms[1] [17]. The mirroring concept—i.e. the exercise that the music therapist practises during the sessions, which consists specifically in acting as a mirror for the client—connects to the mirror mechanism. While this mechanism supports *corporeality*—an intersubjective[2] dimension of our subjectivity, "providing a new cognitive dimension that assists us in defining our nature" (2020)—on the other hand, being connected to the motor system enables the music therapist and the client to organise how the action is executed, and how to perceive and imitate it. The mirroring phase works because, as outlined by the authors:

> When we are present while others are doing something, we immediately comprehend most of their [sensorimotor] and emotional intentions without the need to explicitly represent them linguistically (2020)

In this way, the therapeutic bond is strengthened, making the therapeutic sessions more profitable. Therefore, through music, the innate musical potential present in

[1] FOR further reading, see Lorenzo [19] and Rizzolatti and Sinigaglia [20].

[2] The conjunction of the dimension of *otherness* with that of identity. For further reading, see Gallese and Guerra [17].

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every human being is used and developed, and through the connection between musical technology and musical therapy, these characteristics can be reinforced. With an EDMI, it is possible to access this innate potential by acting on each phase from which the session is composed, and by structuring interventions that aim to reinforce social skills and expressiveness, regardless of physical and/or psychological challenges, technical skills or the musical training of each person [21].

Although the importance of using virtual and immersive technologies in sessions is starting to be understood, we are still far from being able to systematically apply immersive technologies in this field. This is due to an outdated misunderstanding that considers the implementation of the technological instrument too difficult and its scarce potential if compared to the traditional musical approach. Fortunately, this 'dated' consideration is being overcome, even through the period of isolation we have experienced in the last 3 years. As different authors have outlined [5, 22, 23, 24], technology should be implemented in music therapy considering its efficacy and the remarkable demand for applied technology in clinical practice sessions.

As already mentioned, this limitation is motivated by the inadequate technical and theoretical training of professionals. In fact, both research and the systematic application of EDMIs and DMIs in music therapy are scarce and largely consist of pilot experiments or technological prototypes from research projects, which—once such projects are completed—are hardly available or unavailable for sale, are prohibitively expensive, or cannot be accessed in the places where therapy is carried out.[3]

13.1.2 EDMIs with Therapeutic Purposes

Several scholars have pointed out the importance of technology within music therapy practice in the past few decades. One of the conclusions that emerged from a review by Hahna et al. [25] was that digital technology had been successfully applied for assessment and evaluation purposes in music therapy, as well as providing clients with a new, more creative approach. Although dated, this review is valuable in that it highlights the importance of the evaluation component in music therapy and the benefits of technology in enhancing the client's expressivity. This last observation anticipates significant changes in the coming years in music therapy sessions. Some of these have been accelerated by the new need for virtual interventions provoked by COVID-19, while other more gradual changes have witnessed the inclusion of music technology in school curricula or in the latest editions of music therapy manuals.

In the music therapy field, there are still major problems in terms of the flexibility to accommodate diverse learning abilities in the technological area, as these devices require extensive training in computer science [5, 26]. From the client's perspective,

[3] For an example of a pilot experiment with an EDMI for Music therapy, see Motion Composer™ in [21],for an example of a research project on multisensorial technologies, see the RHYME project in Cappelen and Anderson 2016.

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however, one of the greatest obstacles is musical expression itself: not everyone can play a musical instrument or follow a rhythm by coordinating their movements. In fact, the majority do not have the adequate notions or skills to facilitate communication during therapeutic sessions for either party. This presupposes an indefinite number of sessions in which to develop a relationship based on free expression insofar as it will be limited by the knowledge and possibilities of the client. In other words, this lack in musical knowledges poses a threat to the mutual collaboration, making it more likely that a hierarchical one will be established to the detriment of the customer's expressiveness.

In the digital era, technology is a medium in the relationship between a person's inner world and the external world—an extension of ourselves. From this point of view, there are DMIs that can mediate the needs of the patient and the therapist (whether it is through music therapy or physical rehabilitation). This mediation takes place through proper engagement. DMIs can take the shape of traditional instruments, or something quite different, as they contain a sound generation unit and a control surface that can be separated [27]. DMIs can be used in multiple contexts, providing benefits for both experts and non-experts in artistic and musical fields (2006). When referring to DMIs, I distinguish between DMI and Extended DMIs (EDMIs), where the body itself becomes the digital musical instrument, as the interaction occurs through a correlation between the environment and the agent, making the distributive nature of the space offered to the user essential as its property of manipulation and incorporation. In this sense, motor skills are strictly linked to abilities of sound expression and, in other cases, visual expression. Therefore, given the nature of this performative space, therapeutic and pedagogical learning takes place through movement. This highlights the importance of considering proprioception as a bodily basis for consciousness in music [28]. Indeed, Peñalba outlines that the internal simulation of movement (mimesis) and exploration enable us to understand musical aspects that we would not otherwise understand. This concept can shift within an EDMI, as it implements MOCAP or sensorless systems alongside a performative space where the subject may use their body to explore and play around. One subcategory of motion analysis is the above-mentioned MOCAP, which involves camera-based sensors and systems—Kinect by Microsoft, for example [29]—and is usually preferred in the design of new instruments for musical expression due to its low cost and relative ease of use. Moreover, as Mulder points out [30], alternate controllers include three further subcategories: touch controllers, in which the surface has to be touched physically; extended-range controllers, in which it is not necessary to touch the surface although there are limitations in the range of effective gestures; and immersive controllers, which place only a few restrictions on the user's performance.

Thanks to MOCAP systems, an EDMI can become an appropriate instrument for self-awareness, making movements easier to perform and being equally available to everybody. Moreover, the possibilities that EDMIs encompass reside not only in the therapeutic field but also in the pedagogical and artistic ones, which is why I prefer to refer to an extended DMI rather than just an assistive DMI. In this sense, technology becomes a social instrument for equality, regardless of age, race or above all, disability.

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Below, I will propose three examples of EDMIs that rely on sensory integration. Two of them implement audiovisual feedback, while the third audio feedback.

CARE HERE

CARE HERE stands for *Creating Aesthetically Resonant Environments for the Handicapped, Elderly and Rehabilitation* and stems from a European project. The rationale behind the project was to create an environment that enables the user to express the experience they perceive in it [31]. This concept is applied in technology with the aim of encouraging a greater awareness of one's body and movements in children with neuromotor deficits.

As outlined by Brooks and Hasselblad [32], CARE HERE is based on the concept of *Aesthetic Resonance* [33], which occurs when technology responds to a user's effort immediately and in an aesthetically pleasing way. As a consequence, the subject forgets the intention that prompted them to enact a physical movement, and therefore an effort, to receive feedback [32]. The framework underpinning this project is based on "[…] open architectural algorithms for motion detection, creative interaction and analysis, including the proactive libraries of interactive therapeutic exercise batteries based on multimedia manipulation in real time."

Behind CARE HERE there is another project by Brooks himself called *Soundscapes* (Fig. 13.1). The project consists of an "interactive virtual space" (2004) in a motion capture library and a collection of programs capable of providing indirect feedback with respect to the user's audiovisual gestures to trigger a *feedforward* (*homeostatic control system*, 2004)—in other words, a continuous retrofeeding mechanism that anticipates the result associated with the motor action on the feedback. CARE HERE applies the concept of back-feeding by offering the opportunity to select the type of feedback according to the user's preferences. For Brooks and Hasselblad [32], this opportunity makes it possible to bind the user to the same psychological dynamic that underlies games and video games as it evokes an: "understanding of the causality involved and is analogous to the *flow state* involved in play and game psychology—exhibited when a child is engrossed in a computer game."

The CARE HERE technology is based on a sensor system. An algorithm was applied in collaboration with the InfoMus Lab in Genoa, Italy, using the EyesWeb software, which activates movement to visual feedback, otherwise known as *Silhouette Motion Images* (Fig. 13.2). In addition, the movement was segmented through a special program in order to distinguish the phases of motion from the user's pauses [32].

Sentire

Sentire is a body-machine interface [34] that sonifies proximity and touch to enhance body perception and social interaction. It uses a digital system that mediates body movements and musical sounds in the form of two bracelets, which enables two (or more) people to interact with each other. Audio feedback is heard when proximity and touch are detected. The artwork is thus thought of as a participatory performance in which a guiding performer invites the spectators (one at a time) to interact with him/her while wearing the bracelets for 6–10 min. The interaction develops either

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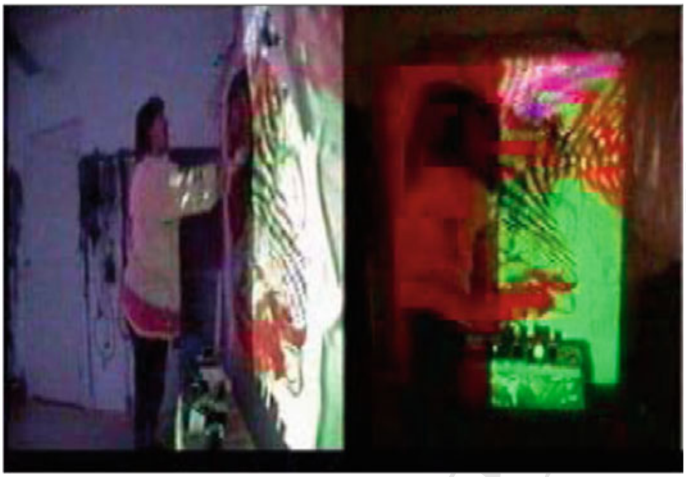

Fig. 13.1 A user during the authors' experiment and the type of visual feedback related to her movement. Reproduced from "Creative aesthetically resonant environments for handicapped, elderly and rehabilitation: Sweden" by Brooks and Hasselblad [32, p. 195] with permission from Brooks

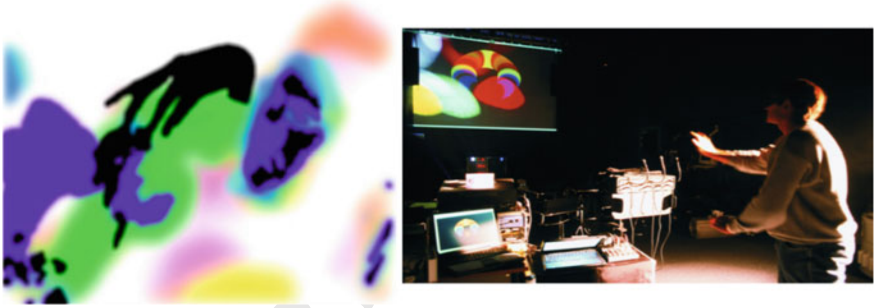

Fig. 13.2 Head/hand within an Eyesweb Bodypaint Aesthetic Resonant Environment on the left and the prototype enabling gesture control on the right. Reproduced from "Soundscapes: the evolution of a concept, apparatus and method where ludic engagement in virtual interactive space is a supplemental tool for therapeutic motivation" by Brooks [31, pp. 17, 12] with permission from Brooks

standing (with eyes open) or sitting (with eyes closed), yet always in a non-verbal context (Fig. 13.3).

Driving this technology is the belief that auditory feedback has the potential to increase embodied experiences and coordination for therapeutic purposes [34]. Distance and touch between the users can be measured and mapped in real time to an algorithmic sound environment [35], making it possible to digitally design real-world proxemics [36]. Through this multimodal experience, an awareness of the self and the other is enhanced on bodily—especially kinaesthetic—levels, i.e.

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Fig. 13.3 Two users of Sentire, reproduced from https://www.interaktive-technologien.de/projekte/sentire by Lussana 2019, with permission from Lussana

movement perception [37, 38]. During the interaction, a process of co-determination occurs, creating a so-called perception–action loop [39]. Since 2019, Sentire has been embedded in a research project at the Humboldt University of Berlin. It is now developed for therapeutic purposes, taking into consideration the increasing incidence of social isolation, chronic stress, and diminished body awareness caused by psychosomatic illnesses and mental disorders.

E-Mocomu

The e-mocomu prototype denotes e-motion, colour and music, and is an EDMI developed under an interdisciplinary perspective with the primary aim of enabling users to control sounds and colours through their movements in space. E-mocomu stemmed from an interest in synaesthesia—in particular, chromaesthesia (sound-colour)—and the search for a theoretical correspondence between sounds and colours mediated by emotions and to be applied as feedback for the user [40]. In chromaesthesia, areas of the brain associated with the auditory system of the fusiform gyrus are activated together with those involved in colour processing [41]. Diverse applicable theories have been studied—Newton, Munsell, Wells, Scriabin, Marion, Kandinsky and Veronesi. Eventually, in the pilot experiment, the correspondence theory of the Italian artist from the Viennese Secession, Luigi Veronesi, was applied (Fig. 13.4). The artist conducted an in-depth study of music and colours from a scientific-mathematical point of view by graphically representing the duration of notes, pauses and silence and attributing an appropriate colour with a specific brightness variation to each tone and semitone [42]. He also highlighted the correlation between colour and pitch, with lower notes represented by darker colours and higher notes by lighter ones.

The first prototype was composed using a Kinect quartz composer and synapse software. The latter version implemented processing software for an audiovisual

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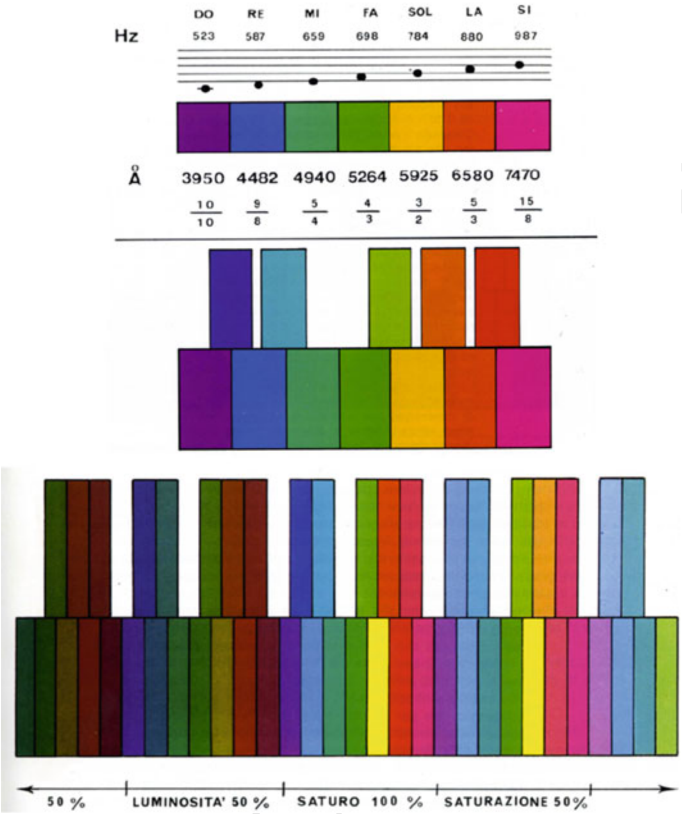

Fig. 13.4 The chromatic and natural musical scale according to the frequency ratios calculated by Veronesi. Below: the piano octaves represented chromatically. Reproduced from "Proposal for a theory on the relationships between sounds and colours" by Luigi [42, pp. 19–21] with the permission of the Luigi Veronesi Committee

output. Once in the immersive space, the user could receive three kinds of audiovisual feedback linked to the body movement within it. No movements corresponded to stopping the EDMI. In an initial study, we analysed the responses of three groups of people to audiovisual stimuli, their learning capacity, and their emotional and improvisational feedback after performing several audiovisual and motor tasks [43]. The results showed a positive self-perceived outcome of the performance as well as a positive boost in self-confidence. A more recent version of e-mocomu was introduced at an *OltreMusica* event in Padua, Italy, in a workshop with people with disabilities from the association (Fig. 13.5). During this workshop, children and people of different ages with and without disabilities—such as autism spectrum disorder (ASD) among others—were able to enjoy a free improvisation session with e-mocomu. The experience was highly rated by the users.

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Fig. 13.5 Images taken during the workshop within *OltreMusica* event at Cooperativa Nuova Idea, Padua, 2019

In the examples proposed here, an EDMI was able to boost progression and development during therapeutic sessions, both in music therapy and rehabilitation. This happens when the user is motivated to work from inside out, which refers to the internal motivation of the user to independently take control of the situation [44]—a condition that occurs when there is freedom of interaction in an interactive environment.

CARE HERE and e-mocomu, in particular, rely on the creative interaction of users, who manipulate the audiovisual feedback with their bodies.

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In yet another study, which dates back to 2010, Camurri et al. [45] tested the *stanza logo-motoria*—an interactive multimodal environment—demonstrating the efficacy of a multimodal system in treating dyslexia within an educational context, and advocating its implementation with ASD clients.

Peñalba et al. [46] note that some interactive musical technologies reduce the differences between users with and without disabilities, bringing both classes of users to the same level of competency as that shown by skilled musicians. In other words, these technologies enable users without musical skills and with physical difficulties to play an instrument properly, and to produce a highly proficient learning and expressive outcome [5, 21].

13.1.2.1 On Virtual Reality for Rehabilitation

The digital landscape has changed radically in the last 35 years, paving the way for new trajectories for expression and creativity in the many fields in which these media are implemented [47]. In this panorama, virtual reality (VR) made its way first and foremost as an innovative tool for entertainment, before entering the pedagogic field known as *playful learning* [48], thus "improving student engagement, promoting creative thinking towards learning and developing approaches towards multi-disciplinary learning." [48]. Moreover, its ecological validity means VR is also widely used in rehabilitation, particularly in motor rehabilitation. As Gallese and Guerra [17] underline, VR has absorbed the models of intersubjectivity and agency experienced in cinema. Cinema, in fact, is an excellent example of a mirror mechanism—a mechanism that supports our intersubjective dimension and provides us with a new cognitive dimension—to understand the direct experience of emotions in the era of interactive technologies and what the authors define as *embodied simulation*:

> [...] a basic functioning mechanism of the brain-body system [...] By activating sensorimotor and visceromotor maps in the brain of the observer this system can facilitate the construction of a direct and non-linguistic relationship with space, objects, actions, emotion and sensations of others. (p. xix)

Therefore, while the application of VR-based rehabilitation can be effective through the embodied simulation mechanism, we should consider it in conjunction with other therapeutic interventions [49, 50]. VR is a valuable option for neurofunctional recovery rehabilitation used with different methods and purposes, such as post-stroke rehabilitation of the upper limbs, for balance, or to improve spatial orientation/navigation and stimulate movement in the lower limbs [51, 52], and through Rehabilitation Gaming Systems (RGS) [53]. The core aim in using RGS is to convince patients that they can perform therapy-related movements, thereby leading the brain to believe that they can perform the simulated movements, while in reality such movements are limited by their disabilities. In this way, it is possible to accelerate the neurofunctional recovery process. As several authors underline [54, 55], rehabilitation in the post-stroke patient is concentrated mainly in the upper limbs because the patient's quality of life depends on them, but also because VR is more effective

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in this sector. Indeed, despite the wide fields of application, it appears that VR and gaming VR are effective in both neurological rehabilitation and in the performance improvement of older adults [56] in upper extremity treatment [57]. Serious game applications—game design for application in fields other than pure entertainment, such as in the learning and rehabilitation context—are still growing and are typically based on MOCAP. This category is the most extensive and most widespread in the current panorama, enabling the extraction of features such as acceleration, velocity and positioning in space in order to understand the behaviour of the subject for therapeutic purposes. It is important to note that accelerometers are still the most used in the technological and artistic-performative field and that, for the most part, they are implemented in other systems [29]. The increasingly widespread use of implementing sensors over other motion analysis techniques—despite being insufficient in certain aspects—is preferred due to their low cost and ease of use (2014).

Among the VR technologies implemented in this field, there is little use—if any—of technologies based on and created with the musical trajectory in mind, such as an EDMI, which uses musical elements with a creative and expressive background. In their research, Stephan et al. [58] claim that "[…] exposure to a movement-related tone sequence can crossmodally and specifically affect subsequent performance of a motor sequence that has never been physically practiced" (p. 7). The authors also highlight the need to understand auditory-motor system interactions in order to contribute to the development of new strategies using sound as a neuromodulatory tool for motor rehabilitation. In another study, Särkämö et al. [59] noted that regular, self-directed music listening during the early post-stroke stage can enhance cognitive recovery, increasing dopamine levels and preventing a negative mood. The authors highlight the importance of everyday music listening during early stroke recovery by providing an individually targeted, easy-to-conduct and inexpensive means to facilitate cognitive and emotional recovery (2008). The use of music in physiotherapy can therefore provide multiple benefits, as it stimulates both sensory and cognitive integration—that is, performing multiple tasks at once, such as singing, tapping, moving, clapping, etc.—which is essential in everyday life. Furthermore, music therapy focuses on the emotional process that psychotherapy usually fails to address. In this way, its implementation would provide additional benefits. The link between motor entrainment and emotional processes is underlined by several authors [60, 61]. In this field, EDMIs could appeal to and be used in post-stroke patients, tackling a rehabilitation issue linked to the monotony of treatment sessions [62]. As expressed by Zagalo and Branco [47], a creative technology must spark interest and be easy to interact with, like a toy, or engage, motivate and maintain concentration while pushing for mastery (2021, 14) among other aspects. These prerequisites should also be considered when designing an EDMI for rehabilitation. By adding a musical component, such as rhythm, we could also consider its therapeutic application in people with ASD, Parkinson's disease, or post-stroke patients who currently demonstrate good responsiveness to treatment with VR. The studies currently available on people with these types of special needs help us to understand that, during the design phase of an EDMI, it is possible to tailor software to the needs of the

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user [5], boosting potential strengths and disregarding any challenges imposed by the disease [63] to avoid potentially deleterious effects [64].

13.1.3 Embodiment, the Environment and EDMIs

EDMIs are technologies applicable in the field of therapy, but which are closely linked to artistic performance and therefore to creative expression [65], the father of *embodiment*, has left us a great philosophical legacy to reflect on—one that helps us to decode interaction and performance from a perceptual-phenomenological perspective. Our body enables us to interact in and with the outside world through movement, and in this digital age in which we encounter more and more interactive experiences [66], this interaction is benefited by technology. Experience is the interpretative key for us to understand abstract domains and is based on the body and on the perception of its exterior. Here, it is the public—who is also the user—who is involved in the creation of their own interactive experience.

When discussing interactive technologies such as EDMIs, we know there is an open dialogue about the meaning of *interaction*, both as a noun and as an adjective [67]. In this chapter, since the EDMI is an interdisciplinary product stemming from both physical and mathematical design alongside a sociological and philosophical concept of the theory of embodiment, the reader will observe that both these aspects are considered.

Working with immersive multimodal environments, it is worthwhile considering the embodied cognition paradigm in order to situate the interaction that occurs between the agent and the environment, such as the sensorimotor contingency theory (SCT). According to the SCT [6], perception and action are interconnected since they influence the configurations of the agent's sensorimotor system (here, the user).

So, when dealing with immersive audiovisual technologies that enhance the user's self-awareness, we need to consider the role of *proprioception*. As indicated by Laskowski et al. [68], proprioception is one of the somatic senses that collects sensory information from the body, although it does not belong to one of the five basic senses. Thanks to proprioceptors, we are aware of the movements of our body in space and are able to control them. In this sense, proprioception can be conscious and voluntary, or it can be unconscious and allow muscle function to stabilise the joints that need to be modulated (1997). It is possible to use the different types of proprioceptors to classify EDMI technologies; for example, in CARE HERE and e-mocomu motor proprioceptors are used, while in Sentire mainly passive tactile proprioceptors and secondarily motor ones play a part.

In the embodied cognition paradigm, on the other hand, the environment is the result of a series of relationships produced by the activity of the subject. According to the enactive approach, the internal world of the subject and the external world in which the interaction takes place are not separate but rather domains that complement each other [69]. The continuous designation of the external and internal domains mentioned above influences perception and action. From the enactive point of view,

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what the subject is able to experience, know and manipulate is influenced by their own structure of being [70]. Therefore, within a responsive environment in which the perception and action of the subject are linked and influenced by the relationship with the space, this perception can increase and stimulate certain behaviours through precise sensorimotor stimulation. Indeed, in the SCT, the interaction between subject and environment is regulated by sensorimotor laws. The ability to master sensorimotor contingencies in every sensory modality derives from practical knowledge [6]. Thus, perception corresponds to changes in the sensorimotor contingencies in relation to the movement of the subject. Within this performative environment, the user's perception is grounded on their self-awareness of bodily changes as a result of their actions. The same actions modify how sensory stimuli are perceived. In this dynamic, the practice leads to a certain degree of control over the object, or mastery. In fact, as explained by Caruana and Borghi [71], the sensorimotor system automatically extracts the 'offers' from the observed objects and encodes them in terms of potential actions.

Among the features of musical creation outlined by Clarke [72], one is particularly meaningful when referring to EDMIs: its intimate connection with environmental affordance. And since we are dealing with EDMIs in which the movement of the subject corresponds to audio and/or visual feedback, the aforementioned concepts lead us to consider the Gibsonian concept of affordance (1998) and to project it into the virtual domain. Indeed, *affordance* refers to the characteristics of the environment offered to the subject: "[…] a point of contact between the creature and its environment, an environment in which the creature moves around and within which it acts" [73]. By transferring these concepts to an EDMI, the affordance is virtual in the sense that it recalls a series of Sensorimotor Maps that the user activates through their exploration of space and the feedback received from the immersive environment (mapping). Through them, the subject is embedded and even extended within the environment. In an EDMI, the client's extended embodiment is implied during the interaction—the user can feel themself directly projected into the environment from a holistic perspective. In this way, the empowerment process appears as a social construct that links the user's inner and outer worlds through technology, which is both social and technical since it is implemented in both settings [8].

13.1.4 Sensorimotor Contingencies, Creativity and Sensory Integration

Despite studies on creativity, what has become apparent in recent years is the need for investigations that focus on the experience, since our body is "the ultimate source of our experience of ourselves and our relationship with the world" [17, p. 11]. From this perspective, studies that establish a connection between immersive technologies, creativity and user empowerment are still scarce.

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Creativity, in fact, is usually associated with an increase in sensory gating and attention control [74, p. 202], while emotional (and mental) processes that regulate goal-oriented behaviour are tied to cognitive control [75]. It follows that an enhancement of sensory gating and attention control is tied to emotional processes and *Creative Empowerment*, a concept described further on, regarding EDMI. Cognitive control "can be understood as emotional process" (2015, p. 8); that is to say that emotion and conflict lead to cognitive control. Thus, emotion is paramount in eliciting and regulating conflict. In fact, as the authors outline: "There are many reasons why emotion would play an important role in the engagement of cognitive and behavioural resources to resolve conflicts [..]" (2015, p. 6). That is to say, emotion regulates goal-oriented behaviour (and cognition) by capturing attention and mobilising an organism for action, as well as helping promote adaptive behavioural responses to handle conflict.

Various authors [76–78] claim that brain imaging studies reveal an apparent connection between mental disorders and high levels of creativity as a result of shared brain characteristics. In fact, creativity appears to be influenced by a multitude of genetic variations [79]. On the other hand, music and music-making can be considered creative actions. Music is a universal language and represents a multisensory experience—both perceptive and physical. It has already been demonstrated that it affects the nervous system by altering levels of dopamine, norepinephrine and serotonin [80]. Moreover, exposure to music enhances brain plasticity and facilitates a wide variety of emotional and cognitive functions besides having a generally positive effect on post-stroke patients [59]. In the rehabilitative field, Riley et al. suggest [81] that technologies aimed at improving the daily life of people with dementia can foster creativity and help them perform different tasks that empower them. This statement is also valid for people with various kinds of disabilities, as well as in the pedagogical sphere, for clients and professionals alike [82]. Riley et al. [81] also highlight the importance of active music-making as an enjoyable tool and a potentially empowering experience. An effective way to apply these concepts to EDMIs, considering the mechanisms underlying cognitive control and the reward system, is reinforcement learning. Reinforcement learning is based on reward prediction error (the difference between the outcome of a choice and the chosen value) and value functions (estimates for the sum of future rewards) where the actions of the organism are chosen probabilistically and which ultimate goal is in fact to maximize future reward [83].

In light of these considerations, an EDMI could also be effective in rehabilitative recovery and in music therapy sessions, for example, through rhythm. The importance of rhythm in this field has been addressed in the past 15 years for its efficacy in treating people with diverse disabilities [64, 84] both in physiotherapy and in music therapy rehabilitation. Within music therapy itself, there are different methods that apply rhythm in the sessions, such as functional music therapy and neurologic music therapy, whereby the latter focuses on improving the client's speech and timed movements [84]. At the same time, neuroscience has shown that the integration of various sensory modalities occurs in the human brain [85]. Thus, the kind of performative experience that users have with technology should be aligned to provide

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them with a form of *coherent multisensory integration* close to what they experience in the real world, and one that could be strengthened through music. This situation—coherent multisensory integration—may occur and be strengthened within a performative technology with multimodal feedback, which reproduces a synaesthetic experience. As Custodero [86] points out, clear feedbacks are paramount for achieving a state of *flow* and thus a creative experience. For [87], however, sensory integration helps develop an adaptive response on both the subcortical and cortical levels, which involves cognitive and emotional processes, providing the material upon which to work in therapy. Its inherently multisensory characteristics mean that music can already give us diverse feedback such as auditory, visual (the score) and bodily feedback (2011). The studies conducted by Koelsch [88] and the reviews by Lin et al. [89] indicate that music therapy improves non-verbal communication, in addition to social interaction and self-expression, which are key factors in controlling the client's depression and anxiety. Somatic and cognitive anxiety can indeed be reduced in people with a moderate and high trait through music treatment [90]. From this perspective, interactive technology aimed at clients with SLD should typically offer programs that can be modified in real time, according to the participant's behaviour; ones that are capable, for example, of recognising the direction of the subject's eyes for a continuous (non-aggressive) interaction; and ones that offer a risk-free environment for the client. The ECHOES project [91], for instance, proposed learning activities for clients with ASD with different objectives and which change according to the attention of the participant and their exploration of the environment. Considering these statements and given the importance of sensory integration in children with ASD, existing interactive systems could become a valuable tool in enhancing expression and creative play. Moreover, music technology has great potential by offering a multimodal approach with tangible interaction design, oriented music therapy and empowering thinking [92].

According to Clarke [72], a creative process occurs through sensorimotor engagement, among other aspects. Likewise, for the SCT [6, p. 572] the experience appears to be a temporally extended exploratory activity mediated by the subject's sensorimotor contingencies. Therefore, sensory perception is the "ability to explore one's environment in ways mediated by implicit knowledge of patterns of sensorimotor contingency that govern perceptual modes of exploration" (p. 569). Indeed, it is an association of different perceptual-sensorial modalities of which the subject is aware, even at an implicit level. In other words, perception is formed through changes in sensorimotor contingencies that the subject perceives during their movement to reach the initial stimulus (i.e. moving towards an object). While moving, however, the perception of the subject will change, since the information provided by the stimulus will change in relation to the movement itself. Movement and proprioceptive perception are therefore the basis of a co-determination process that is generated during perception and action—through *Multiple Affordances* and *Sensorimotor Maps*, which I will explain in the next paragraph—and which occurs within an EDMI where the user's capacities are empowered and enhanced [5].

Hence, as also emphasised by the SCT, we experience the integration of different sensory modalities through movement, while different physical explorations

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encourage different perceptual modalities. In this regard, Ruggieri [93] argues that the interaction in space is always synaesthetic since it is linked to the interaction of different sensory modalities in real time. For the author, space and movement are intertwined and the body image is processed based on perceived sensory information, which can be of a different nature (tactile, proprioceptive, sound, etc.). In "constructing the image of their own body, the different subjects can favour one sensory modality over the others, using, for example, mainly the visual channel over the cenesthetic or acoustic one and vice versa" (1997). In this way, it is the subject who unconsciously chooses what sensory information to prioritise.

In the examples provided in paragraph 1.2 and in the description of the BehCreative pilot experiment in 1.5.1, the designers pursued the goal of integrating different sensory modalities within an EDMI, to offer a complete user experience. This way, the user encounters a feeling of *non-mediation*: in other words, the technology disappears [94] or becomes an extension of the body [8]. Effectiveness, however, will depend on the subject's creative and emotional processes, aided by the design of the EDMI itself as adequate tool for Creative Empowerment to occur. Furthermore, according to Gallese and Guerra [17], contemporary cognitive neuroscience is able to investigate the fundamental role of the body in creative expression and its reception—a current field of research, according to the authors.

For these reasons, a technology-driven shift in performative spaces needs to be encouraged, based on general theories on cognition, emotions, creativity and music-related neural activation. To do so successfully, it should engage the field of neuroscience to better understand the underlying mechanisms.

13.1.4.1 Sensorimotor Maps and Multiple Affordances

The body assumes great importance in the process of physical and phenomenological understanding. Together with the body, technology as an art form becomes a useful tool in understanding the relationship between internal and external dimensions. Therefore, in the performative act and within an immersive technological space, the subject continuously changes their body map by restructuring it. This also happens through their incorporated perception, as underlined by Kozel: "Performance is never one-directional [...] performance involves the awareness of being in a state of reception and initiation between inside and outside, modulation and response" [95].

Alongside the concept I refer to as *sensorimotor map* is that of *cognitive map,* developed by Benford and Giannachi [96], which indicates the continuous adaptation undertaken by the user in a mixed environment—i.e. both real and virtual—which obliges them to continuously monitor and engage with the two realities through the perception and use of these cognitive maps. Here, the concept of a sensorimotor map already incorporates the cognitive dimension. Within an EDMI, proprioception plays a fundamental role in the creation of Sensorimotor Maps since the participant is offered not only a free choice of movements based on their exploration of the environment through sensorimotor contingencies, but also free artistic expression,

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of which they are the direct protagonist. According to the SCT and the concept of the sensorimotor map proposed here, the sensorimotor contingencies within an EDMI will depend on the proficiency acquired by the subject through practical knowledge. That is to say, the user will perceive changes in the different sensory modalities through their movement, heightened by the technology in which they are immersed, and will learn to master them. Furthermore, when using an EDMI, the individual should know which movements produce specific feedback, and it is precisely through the SCT that the user constantly verifies that their actions are the ones required to produce the expected result, thus satisfying their expectations. In this sense, the user charts their own Sensorimotor Maps, stemming from exploratory movement and which will enable the creation and use of Multiple Affordances. They will also allow for the storage of information and experiences encountered within the EDMI. It is precisely through these movements, provided by an exploratory experience, that the user will achieve full control over the technology, reaching *Creative Empowerment*.

Being aware of sensorimotor contingencies means knowing which movements are necessary to produce certain changes, even in technological design, and which sensory modalities guide us towards the movements aimed at obtaining them. Therefore, depending on the type of technological instrument that is used, there will be a different sensorimotor pattern.

These reflections express the concept of *Multiple Affordances*. With this term, I intend to define the presence of more than one affordance, whether potential or real, which are available within the interactive space to the user. As summarised by Anderson and Sharrock [97], the affordances of objects are "constructed and reconstructed in and through the courses of actions in which we engage" (1993). Within an EDMI, however, there are no physical objects, so affordances depend on the body parameters identified through Sensorimotor Maps and mapping. Hence, these affordances represent the possibilities of the subject to interact with the immersive space through the Sensorimotor Maps constructed internally. In particular, Multiple Affordances continue to develop and change depending on the level of control and experience that the subject obtains. Therefore, the more the user reacts and interacts with the feedback, the more the affordances will transform. In other words, the level of experience can pave the way for much more complex actions than those 'suggested' by the object at the beginning of the exploration. Furthermore, Multiple Affordances can be used and explored voluntarily by the user.

Ultimately, since our body is "a priori the ultimate source of our experience" [17], to study the relationship between the body and the immersive environment—without forgetting the concept put forth by the authors of *Embodied Simulation* (see 1.2.1)—we should remember the importance of our motor system, which is activated even when we are stationary, but are incorporating a simulation mode of what we have seen into an inner understanding (2020). In fact, within an EDMI, the user moves with intent to explore the space and to interact through different phases, thus creating new Sensorimotor Maps or repeating those already internalised organically or learned during the explorative experience. As the authors [17] argue, "a movement is a simple dislocation of body parts, like flexing and stretching fingers. A motor act, however, consists of using these movements to attain a motor goal […]" while "the

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premotor neurons are much more sensitive to the goal behind the action than to the individual movements necessary to attain it" (2021). A central point of this discourse concerns the goal of this interaction or the goal of the user specifically, which, in the case of EDMIs like those described here, are based on movement for expressive and creative purposes. Therefore, the act of learning through a creative experience within an EDMI is fuelled by rewarding emotional expectations and triggers Creative Empowerment.

13.1.4.2 Empowerment

The term *empowerment*, coined by American psychologist Rappaport, dates back to the second half of the twentieth century and was later adopted by other disciplines such as politics, psychotherapeutic treatment, pedagogy.

There are several definitions of empowerment. Among these, it is important to report that of Kiefer [98], for whom it represents a process of acquiring skills, abilities and information useful for the social and individual aspects of people. According to Zimmerman [99], "Empowerment suggests a distinct approach for developing interventions and creating social change".

At the basis of empowerment is collaboration, which sets the psychology of empowerment apart since the professional cooperates with the client rather than acting as an expert, thus avoiding passive acceptance by the client.

In the field of music therapy, is the concept of empowerment proposed by the music therapist Rolvsjord, who in 2004 argued that there are different types of interaction—subordination, collaboration, domination—according to the client's needs. The author talks about psychological empowerment and the importance of this within music therapy, recognising the various advantages it brings to sessions, referring in particular to cases of senile dementia she has treated [100].

According to Rolvsjord, different definitions of this process exist precisely because of this multi-level construct. According to the music therapist, one should employ a resource-oriented, collaborative and participatory approach. Furthermore, the concept of empowerment raises questions about general and individual intellectual health as well as therapeutic practices. This concept invites us to observe the therapeutic relationship and its power dynamics, and otherwise implies a political dimension within clinical practice, stimulating a discussion between subjectivity, objectivity, research and politics. Finally, it concerns the recognition of the client's rights in terms of music. Some of these advantages entail a discussion about the nature of music therapy and the health that empowerment affects, as well as the recognition of the client's rights in music therapy. Indeed, focusing therapy on empowerment encourages the client's resource-oriented development and practice, as well as collaboration with the therapist.

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13.1.4.3 Creative Empowerment

This concept is the result of an investigation in the field of music technology applied to the music therapy domain, beginning with the design of e-mocomu and following with the BehCreative environment, where the subject experiences complex audiovisual modalities according to the type of movement they undertake, and in which the movements are related to Gibson's notion of affordance [101]. In fact, as Clarke reminds us [72], Gibson [101] himself defined affordance as the property of the object in relation to the capacities of the user. Hence, it is not a static attribute we simply perceive. As he explains: "affordances are discovered through active engagement" (2021). They are reciprocal, which means that the kind of aesthetic perception we experience in an EDMI can be extremely different between users. Creative Empowerment is the result of specific processes—exploration, Sensorimotor Maps, and multiple trajectories—that happen within the EDMI, between the user and the environment, and which will be described here. To understand this concept, we should adapt the SCT to within the context of an EDMI.

As explained earlier, the sensorimotor contingency within an EDMI occurs through the manipulation and exploration of the immersive space through the subject's movements. This implies the accomplishment of a state of control over technology, or a *flow*[4]—a psychological state associated with creativity (Csikszentmihalyi 1996 in Wilkie et al. [102]), which enables the subject to express themself autonomously and without reservation from a creative point of view. In this case, we will discuss *Creative Empowerment*, which derives from a "feeling of control and self-determination in the client, gained through the exercise of creative expression" [5]. In order for this control to take place, a second person—in this case, the figure of the therapist—may be present to put forth ideas and help the client in the exploratory process, according to the mapping of the technology.

In this way, the subject receives pleasant feedback from the environment and their own body during Creative Empowerment through the self-awareness of their movements.

According to Ruggieri [93], motor activity is the basis of the pleasure-displeasure dynamic, referring in particular to "pleasure as being closely linked to bodily activity". One such example is attention, which is followed by an expectation that corresponds to muscular tension, leading in turn to the muscular resolution triggered by the onset of the stimulus. This "internal feedback" of pleasure, associated with the subject's positive thoughts about their performance, allows for the creation of Sensorimotor Maps following the positive expectations created during the interaction. In this way, the subject can express themself freely through movement in the performative space.

[4] This state is attained in a technological context when: "[i]n order to remain engaging, consuming and flow-like, activities that involve musical instruments must offer continued challenges at appropriate levels of difficulty: not too difficult, and not too easy" (see Csikszentmihalyi, quoted in Wilkie et al. [102]).

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Benford and Giannachi [96] also emphasise the creative aspect in achieving control, particularly in “command-and-control” technologies (p. 7), as they facilitate creativity and play. While Swingler [103] and Ellis [104] highlight the possibilities offered by interactive environments for children with SLD through the concept of aesthetic resonation, Brooks and Hasselblad [32] refer to aesthetic resonance as “a situation where the response to intent is so immediate and aesthetically pleasing as to make one forget the physical movement (and often effort) involved in the conveying of the intention”.

These definitions share a common theme in terms of achieving a state of control, which may be otherwise driven by the therapist’s mediation.

It is useful to note that in Creative Empowerment the music therapist or physiotherapist will intervene to adapt an EDMI to their client, supporting them, albeit without influencing the user’s awareness of movements, exploration, expression, composition or retrofeeding, or the creation of Sensorimotor Maps, which can take place within the same.

Therefore, Creative Empowerment is a condition that is fostered by these extended digital technologies through the self-awareness of movements [5] as well as physical instantiation and situatedness in an environment [67]—that is, interaction. In addition, it is a creative process that does not rely solely on the body-awareness of the user but on the subjective belief of self-efficacy [105] since it comes from the empowerment theory. Moreover, the role of emotions in creative processes is also fundamental and has been studied extensively at an experimental level [106], although none of these studies took place in immersive technological environments. Indeed, given that emotion affects and fuels the creative process [76, 106], intrinsic motivation plays a vital role, based on enjoyment and challenge. The concept of Creative Empowerment is of course grounded in intrinsic motivation, considering that it is a matter of transforming “general and specific skills into creative behaviour” [107].

In this manner, Creative Empowerment is grounded in:

1. A sense of control over the technology; a mastery that leads to a state of flow;
2. The self-awareness connected to proprioception, resulting from a cyclical process of co-determination between the different parts involved (Multiple Affordances, Sensorimotor Maps);
3. A sense of self-efficacy that emerges on a psychological level and arises from the subjective belief that the user perceives about their own creative abilities (2019);
4. The intrinsic motivation that appears when the experience is enjoyable yet challenging.

13.1.4.4 The Conceptual Framework of Creative Empowerment

In the previous paragraphs, I have described the theory of Creative Empowerment, its foundations, and the importance it assumes in various fields such as in music therapy and pedagogy [108].

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It is worth remembering that perception, which in this context concerns sound, image and proprioception, occurs through sensorimotor contingencies; that is, the relationship between the informational changes produced in the environment and the movements produced by one's body. For this reason, there is an interdependence between perception and action, experienced by the user during the interaction. In fact, in the conceptual framework proposed below, action (as an exploratory activity) and perception are two constant and closely linked elements.

In the diagram in Fig. 13.6 we find:

1. Perception of the environment linked to the exploratory experience between agent and environment in an action-perception cycle described by the SCT;
2. Proprioception as the perception of self-awareness;
3. Exploratory experience or the exploration of the environment through the user's movements;
4. Sensorimotor Maps;
5. Multiple Affordances;
6. Mapping.

Sensorimotor Maps are determined by the user's exploration of the environment during their interaction with EDMI technology, by the changes perceived during this

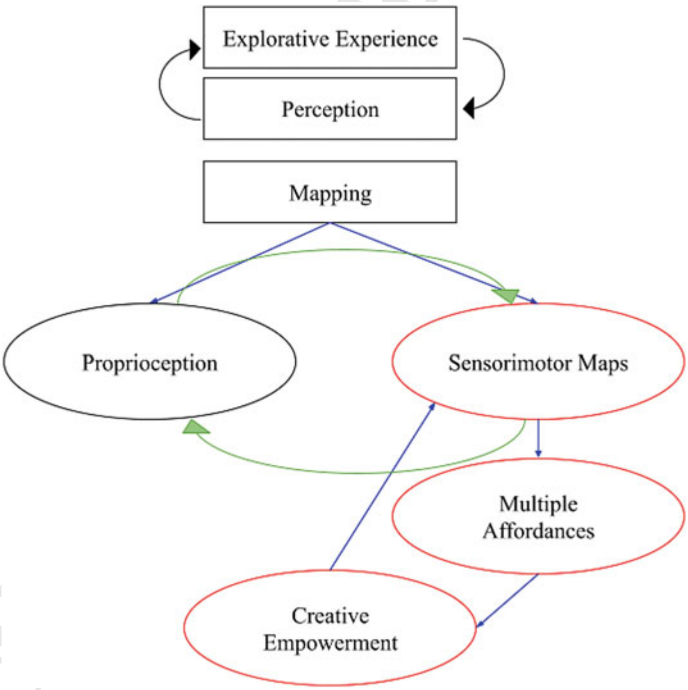

Fig. 13.6 Conceptual map of creative empowerment within an EDMI

exploration of the environment, which also depend on perception, and finally, by the mapping of the technology. The mapping itself changes the relationship between gestures, sounds and/or visual feedback [5] and it is the relation between "the physical interfaces—directly linked to the user—and the logical interface—indirectly linked to the user—forming a unity of mediation, is extremely rich to work on to define the way we would like the user to perceive the experience" [109, p. 532].

In particular, Sensorimotor Maps depend on proprioception as they are created through the movement of the subject and the different perceptual modalities that are activated (visual-proprioceptive, audio-proprioceptive and proprioceptive). In addition, the subject creates their own sensorimotor map through an awareness of their movements in the environment, based on proprioception and their perception of self-efficacy. Therefore, Sensorimotor Maps derive from the subject's perception and their self-awareness of the exploratory movements performed.

Multiple Affordances, however, derive from mapping. They may or may not be pre-established at first glance yet, in any case, they depend on the interaction of the user, who can therefore change the way they interact and use them. In this case, they are virtual and are strictly connected to Sensorimotor Maps, as they are created and recreated continuously (they represent different paths/material that the subject uses and applies for expressive purposes).

The concepts of Sensorimotor Maps and Multiple Affordances converge in Creative Empowerment. The Creative Empowerment of a subject during their interaction with an EDMI allows for the creation of a sensorimotor map once the appropriate degree of control has been reached, as described above. Therefore, while Sensorimotor Maps and Multiple Affordances also depend on the mapping itself, they must be present for Creative Empowerment to occur. As such, co-determination takes place between the action of the subject, with their repertoire of actions, and feedback from the environment.

Mapping is a fundamental parameter because it enables the user to control and play the EDMI, conveying their expressiveness through the feedback set, and allows for data analysis.

13.1.5 BehCreative

The BehCreative EDMI stands for *behavioural creativity* and aims to investigate the physiological, neurological and emotional processes that underlie behavioural changes in the user. In order to investigate functional brain changes, resting-state functional magnetic resonance imaging (rs-fMRI) data was applied.

Behind this decision was the fact that cognitive control is tied to mental and emotional processes that regulate goal-oriented behaviour through conflict [75], mobilising the user's action while promoting adaptive behavioural responses to handle a conflict-driven virtual situation. The fMRI technique is based on nuclear

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magnetic resonance (NMR) and measures the BOLD (blood oxygenation level-dependent) response of the brain—a combination of variations in blood flow, volume and oxygenation—secondary to neuronal activity.

The BehCreative concept relies on the client's motivation, which should be of the utmost importance when designing an EDMI to treat specific pathologies.

As already mentioned in 1.2, an immersive performative space such as an EDMI is a performative space where the subject becomes an instrument, using their body and senses to explore the space offered for different purposes (artistic, therapeutic or pedagogical). Within it, the user feels directly projected into the environment from a holistic perspective. Hence, the performative space or *environment* is crucial.

Another goal of the BehCreative investigation was to set a common protocol by investigating how audiovisual and motor learning generates and strengthens new Sensorimotor Maps based on crossmodal encoding in healthy subjects, measuring the effects in the brains of these subjects, with a view to its future use in the rehabilitation process of people with physical disabilities, such as stroke patients.

The subjects' behaviour within interactive performative spaces and the brain's reaction/response to audiovisual and motor stimuli can be measured by conducting appropriate studies using functional magnetic resonance imaging (fMRI). The investigation also aims to measure how subjects engage with an interactive environment on the assumption that their actions are mediated by their motivation and perceptions.

Since it is an immersive environment, and due to its flexibility, BehCreative can be tailored to people with a vast spectrum of health issues or special needs.

In designing this performative space, we attributed audiovisual feedbacks to the subject's positioning of their left and right arms. The visual was then projected onto the walls in front of and to both sides of the subject. We also implemented pure data and processing programs connected through the open sound control (OSC) protocol. Another music software was applied for sound synthesis and audio tracks, while Kinect 2 was used for body mapping. We video recorded the performance of each subject to retrieve qualitative data. For quantitative data, we collected the *jerk*[5]—the derivative of body acceleration—to calculate the motion fluidity of their performance and provide the appropriate audio feedback. It is motion fluidity that influences the degree of dissonance or consonance that subjects hear from six of the eight loudspeakers while interacting with the EDMI during each session. For this reason, we collected the jerk of the body to calculate the motion fluidity of the users. Furthermore, we collected and established beforehand six specific arm movements (three per arm) for the two subjects, which we included in the multiple affordance category and named *virtual affordance* (VA). The type of sound corresponding to these movements came from two of the eight speakers in the studio, located behind the performing subject.

[5] Jerk is defined as the rate of change of acceleration; that is, the derivative of acceleration with respect to time and, as such, the second derivative of velocity or the third derivative of position.

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13.1.5.1 Creative Empowerment in BehCreative

Previous studies with fMRI outlined how patients presented significant changes in their perception of emotions and modulations of the connectivity of the cerebral network [110, 111]. Emotion can be described as a perception-valuation and action process [112] in which an input from an internal or external world is perceived and then triggers an action that alters it. It depends on stimuli that can have innate value or acquire value and has a process of valuation (2015). At a neural level, emotion engages the amygdala, the ventral striatum and the periaqueductal grey (PAG) matter, besides a set of cortical regions such as the anterior insula and the dorsal anterior cingulate cortex (dACC). Hence, multiple anatomical regions are associated with emotions. As explained in paragraph 1.4, emotional process fuels creative process, which is thus the result of an intrinsic motivation such as a reward. For this reason, we can consider Creative Empowerment as depending on the reward feeling pursued by a goal-oriented behaviour, regulated by emotional process and cognitive control.

Here, I describe the data in a former pilot study of two volunteers. The study was structured in two phases: exploration and improvisation. The users' movements were tracked with Kinect 2 and the corresponding visual feedback was displayed through three screens around the user. As for the audio feedback, an octophone system of loudspeakers surrounded the user. Six specific sound sets linked to arm movements were produced by two loudspeakers to offer the users virtual affordance, while the others were linked to the jerk. Audiovisual feedback was bonded, with the colours displayed during certain precise movements (VA) linked to specific audio feedback. More specifically, colours themselves were linked to consonant sounds, while the absence of colour (white) was linked to dissonant sounds. Figure 13.7 shows some of the visual feedback.

Data from the rs-fMRI was analysed in the same way as that described in Feitosa et al. [113]. The degree of the obtained graphs was computed for the two moments data was acquired, as well as the degree of changes between these moments, analysing degree (K), clustering coefficient (C) and betweenness centrality (BC) over the cortex in ten fMRI evaluations and displaying here the first and the fifth ones. Through qualitative analyses, we see a different albeit markable transition from the 1st to the 10th session. The two participants demonstrated a distinct first approach and general interaction with BehCreative technology [114].

As described elsewhere (2020), the graphs in Fig. 13.8 show the varied activation of brain areas other than the visual cortex (peristriate of Broadmann area 19). The first subject shows consistency of clustering coefficient (C) through activation of the visual cortex, underlying alertness and high attention; the prefrontal cortex (PC) for the motor system; and minor activation of the area responsible for the cognitive process of decision-making (orbitofrontal cortex). In the second subject, the most significant increase occurs in the anterior-prefrontal cortex, responsible for the strategic processes in memory recall and cognitive control that facilitate the attainment of a chosen goal. This is particularly important when referring to the rewarding system. Moreover, other significant increases occur in the extrastriate cortex, which has multimodal integrating functions, and in the temporal lobe

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Fig. 13.7 Three users during the experiment: coloured feedback is linked to consonant sounds and VA; white visual feedback (the absence of colour) is linked to dissonant sounds and no VA

(area 37), which processes sensory input into deriving meanings for the appropriate retention of emotional association with others.

Overall, C underlines the largest changes in the second subject—the one with more bodily knowledge. Furthermore, we observe new brain connections over the sessions and a contingency of data between virtual affordance, the questionnaire on self-perceived performance, and fMRI data, revealing an increase in the calibration of motion fluidity (control over the environment) and self-awareness in the daily practice of BehCreative (2020).

These findings can be correlated with the concept of Creative Empowerment linked to the reward circuit (2020). Nevertheless, we are running a more in-depth experiment so further data will be published.

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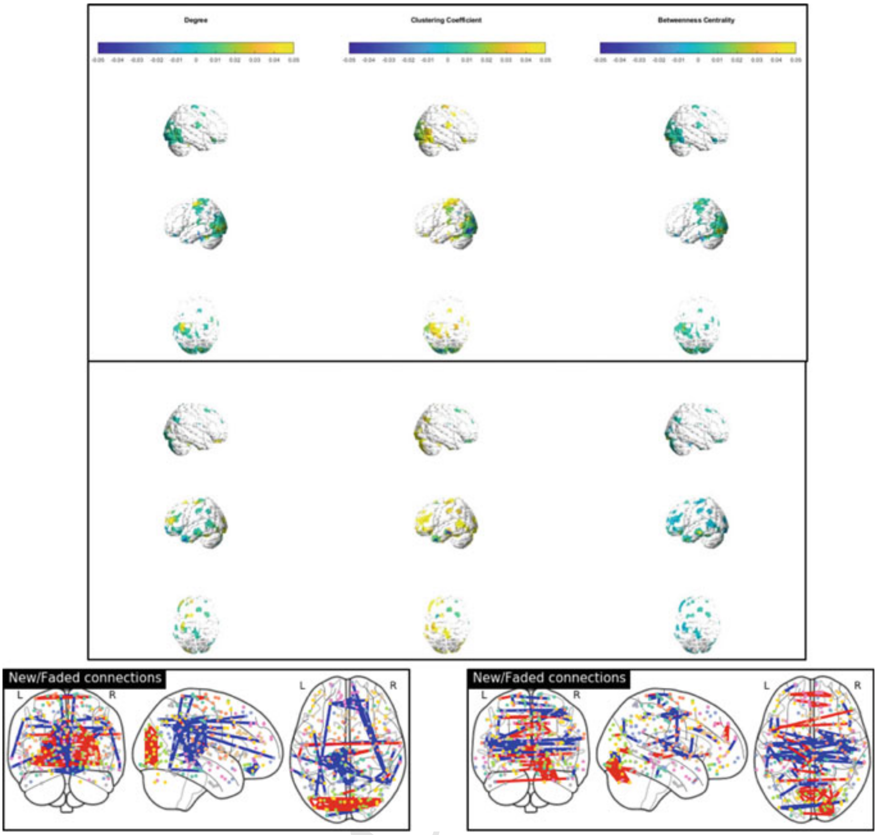

Fig. 13.8 Graph metrics detailing relative changes between fMRI sessions and new versus faded neural connection of 2 subjects from sessions 1–5

13.1.6 Phases of the User's Creative Involvement Within an EDMI

From what has been described so far, it appears that our perception is essential within an EDMI in order to plan a movement, regulate it, perceive it and store it in our memory, and to be able to reproduce the same movements at a later time through what we experienced and the resulting Sensorimotor Maps.

Below, I present the movement of the subject as being key to the improvisation and self-expression that occurs within an EDMI. I summarise this performance in four stages of implication that enable the creative expression of the user:

1. *Environmental exploration.* This phase involves an initial aleatory exploration of the subject to understand the type of interaction that exists with the technology. This experience is connected to the theory of sensorimotor contingencies and enables us to learn the rules that determine how EDMIs function.

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2. *Programming (and re-programming) of Sensorimotor Maps.* This phase involves the creation of Sensorimotor Maps through interaction with Multiple Affordances and the subsequent consolidation of these as a result of the exploratory practice.
3. *Memorisation.* This phase is strictly connected to the previous phase given that it involves the subject's memorisation of the experience gained within an EDMI that is useful for a new or future interaction with technology, drawing on [115] concept of a motor prototype of predefined affordances that are activated when observing an object. The Sensorimotor Maps created in the anterior phase are linked to the concept of motor prototype, since they are stored as predefined so as to be automatically re-proposed in future interactions with the same technology.
4. *New programming.* The subject will be able to search and use new affordances, returning to point 2. In other words, the subject will use the material available to them in ways that could differ from the first exploratory experience.

In terms of these points, it appears there is a certain circularity between phases 2, 3 and 4.

Therefore, within a creative space such as an EDMI, co-determination is generated by the interaction between the agent and their environment. Here, embodiment is necessary for interactivity to happen [67] in an action-perception cycle.

13.1.7 Future Perspectives

In the digital era, programming and designing new interfaces for creative musical expression is easier than in the past. The technological period in which we live has changed not only how music is listened to, produced and distributed, but also and above all the ease with which it is used for creative purposes. Let us consider, for example, low-cost technologies such as the Microsoft Kinect camera-based motion tracking system, created in the Microsoft Xbox package for entertainment and later implemented for multiple applications by programmers around the world. In this interdisciplinary panorama, it is clear that if we merge the humanistic field with the therapeutic and pedagogical ones—that is, by offering immersive and extended musical technologies for creative purposes—users may benefit from this potential and develop it in a multitude of ways.

As evidenced in the literature, music technology for therapeutic purposes embraces a vast range of fields and discourses, from an organic perspective in motor rehabilitation and RGS [116] to an emphasis on identity construction in music therapy sessions [117]. In light of the global pandemic we just experienced, it would also be logical to design effective EDMIs that can be applied remotely between the user and the therapist, both in music therapy and in post-stroke rehabilitation, in order to provide a continuum in the patient's rehabilitation process outside the clinical setting [62, 82]. This is not only because of the low cost and accessibility of MOCAP system technologies, but rather because they make it possible to shape the design to the client's needs.

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Ultimately, there is a need today for a common protocol for a holistic evaluation of the subject [87, 118] and a research project on creativity, especially within immersive environments such as EDMIs.

As music becomes more accessible through creative technology, the instrument is no longer just an object. In fact, it is now a possibility in the hands of the therapist or caregiver to help assist and develop the user's ideas, enabling their self-expression free from the limitations associated with traditional musical instruments and thus tightening the therapeutic bond for effective intervention. In this way, the client can trust in their abilities since it is through creative expression in a performative process that they immerse themself in this interactive technology. So far, I have mentioned the possibility that the user, as protagonist of the experience, is supported by a therapist. Clearly, in the case of remote rehabilitation, it would be the caregiver who assists in the session. An EDMI is essentially a musical instrument that expands the possibilities of the user on a practical level. On that account, we could also invite more than one user at a time, as typically happens in music therapy sessions. In this case, and again, depending on the field of application, we could gain further benefits from social interaction. Indeed, collaborative creativity in music making helps people to communicate together [119]. Since music has an intrinsically social nature, working in groups can produce a beneficial effect (2021). Cappelen and Andersson [120] underline the importance of facilitating musical co-creation between users by offering them the opportunity to shift roles dynamically (2011). In this way, the interactive technology designed is open to a myriad of interpretations, interaction forms and roles to try out (2011). This approach highlights the nature of the creative process in music, which can be both social and collaborative as well as individual [121, 122].

Indeed, on the therapeutic side, a clinical approach also involves the implementation of new technologies, and professionals in these fields should be open to its implementation and development in order to stay at the forefront of innovation [5, 123]. This implementation calls for co-design, which should involve users with a varied grade of disabilities in order to create a flexible, equitable environment and stimulating sensory experiences [7, 87, 124, 125] also focusing on the expertise that stakeholders bring into the design process and on a mutual learning approach between adults and children[6] [126, p. 10]. All of these considerations are paramount for reaching Creative Empowerment [5] and a failure-free system [81] by the user.

To conclude, by means of a sensorless EDMI tailored to their strengths, users can interact with their environment and create new forms of expression, finding the motivation they need to recover their well-being through a positive, rewarding experience.

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[6] For more information, see the FUBI method in Schaper et al. [126].

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13.2 Note

In the chapter the author refers to “subject, client, user” as to the agent that performs within the immersive reality environment such as BehCreative and other EDMIs.

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