Rafael Ramirez-Melendez

Neurocognitive Music Therapy

Intersecting Music, Medicine and Technology for Health and Well-Being

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A Rosanna y Raul, con todo mi amor

Preface

For millennia, music has served as a profound medium for evoking emotions, facilitating communication, and nurturing overall well-being. As a consequence, music-based interventions have emerged as a remarkable force in promoting health, aiding in healing processes, and facilitating rehabilitation. The dawn of sophisticated neuroimaging technology has revolutionized our perspective on human responses to music, providing us with an unprecedented window into the intricate connection between music and the brain. As scientific knowledge regarding this intricate relationship continues to advance, so too does our understanding of how music-based interventions can be optimally harnessed to enhance the lives of individuals suffering from neurological and cognitive impairments. This book explores the cutting-edge insights and transformative potential that arise from neurocognitive music therapy combining music, neuroscience, and technology to produce therapeutic tools and procedures.

The aim of this book is to provide an overview of how neurocognitive music therapy and technology can have a huge impact and direct implications in the practice of evidence-based music interventions. In particular, we describe research and research-based procedures to improve the condition of individuals with depression, autistic spectrum disorder, cerebral palsy, cancer, and stroke. Music-based interventions in this context have the ability to facilitate cognitive and emotional processing, enhance communication, and promote motor rehabilitation, while current technologies provide new opportunities to evaluate, validate, and potentiate music-based interventions, allowing new and innovative possibilities and more personalized interventions.

This book is the outcome of many years of fruitful interdisciplinary collaboration between clinicians, music therapists, mathematicians, computer scientists, and neuroscientists. The collaboration of these diverse professionals has forged new pathways, developing evidence-based interventions that harness the healing potential of music, ultimately enhancing the well-being and quality of life for individuals across diverse populations. Music-based interventions have a huge potential to improve the lives of lots of people. I hope this book will contribute to the growing body of knowledge in this field, and inspire further research and innovation in the practice of music therapy.

Barcelona, Spain Rafael Ramirez-Melendez

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I owe the deepest gratitude to my parents, Alfonso and Linda. Every word I pen, every thought I conceive, everything I do traces its origins back to the home you provided and the infinite love you showered upon me. Without you, nothing.

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Thank you to all of you.

Contents

Chapter 1
Introduction

Contents

1.1 Music for Health and Well-Being

Throughout our evolutionary journey, two universal features have played a significant role: our innate ability to create and respond to music and our instinct to sing and dance in sync with the rhythm of music. As our ancestors possessed limited language skills but rich emotional expression, they began articulating and gesturing their feelings, focusing on denotation (i.e. literal meaning) rather than connotation (i.e. intension meaning). However, it is reasonable to believe that music emerged as the most advanced form of connotational semantics preceding the establishment of meaning through words. Thus, music became an integral part of our human experience, predating verbal communication in its ability to convey profound emotions and meaning.

The profound connection between music and emotion has been widely acknowledged. Music possesses a universal quality that is deeply ingrained in our evolutionary development, capable of eliciting significant changes in our emotions and behaviours. From an anatomical perspective, the association between music and brain suggests that music acts as a powerful stimulant. Notably, studies have demonstrated that rhythmic entrainment, facilitated through music, can aid in the recovery of motor function in individuals with stroke, Parkinson's disease, cerebral palsy, and traumatic brain injury. Additionally, research on individuals with memory

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disorders, such as Alzheimer's disease, indicates that musical memory traces are deeply ingrained and more resilient to neurodegenerative effects. Research suggests that music therapy is useful in individuals with depression and is associated with improvements in mood disorders. Furthermore, music interventions show potential in treating neuropsychiatric disorders, including autism spectrum disorders, as they aim to evoke emotions directly. Music has the power to induce strong emotions and effectively impact the mood of individuals (Sloboda 1992; Juslin and Västfjäll 2008; Koelsch 2010a). Research involving neuroimaging techniques has shown that emotions evoked by music can modulate activity in virtually all limbic and paralimbic brain structures (Koelsch 2010b, 2014). Thus, music is often used as an adjunct therapy in a variety of clinical conditions (Degli Stefani and Biasutti 2016; Biasutti and Mangiacotti 2018).

The use of music as a therapeutic tool is not new: Music has been used to promote health and well-being throughout history and across cultures (Gouk 2000; Horden 2001). From Egyptians (frescoes from the fourth millennium B.C. illustrate the use of music in therapeutic contexts) and Greeks (Xenocrates and Sarpander used harp music and rhythm to control seizures and heal illnesses) to today, music has continued to be used for health and well-being in most cultures worldwide. Recently, music therapy has been established as a health profession in various countries, in great measure due to the fact that over the past few decades, a large body of evidence has been gathered, indicating that music has significant benefits for health and well-being that go beyond mere leisure and recreation.

1.2 Music Therapy

Music therapy (MT) involves a specific set of practices requiring intensive training in professional programmes (nowadays, there are numerous degrees, master, and PhD programmes offered by prestigious universities). It is based on the therapeutic aspects of music. According to the American Music Therapy Association, "Music Therapy is an established health profession in which music is used within a therapeutic relationship to address individuals' physical, emotional, cognitive, and social needs" (American Music Therapy Association 2017). Music therapy techniques depend crucially on the specific nature of the problem, whether neurological (e.g. stroke, Parkinson's disease), psychiatric (e.g. depression), developmental (e.g. autism, learning disability), or coping with serious and challenging life circumstances (e.g. palliative care, oncology).

Techniques used in music therapy are often classified as receptive (or passive) and creative (or active). *Receptive music therapy*, in which the patient listens to recorded or live music in order to achieve a desired outcome such as reduced anxiety, is most appropriate in circumstances where active music participation is not possible or desirable. In *guided imagery and music* or *imaginative receptive interventions*, music listening is used to evoke a situation or inner experience in the form of therapist-assisted mental imagery (Trondalen and Bonde 2012). In addition to being a relaxation technique, this imagery may also be used as a basis for therapeutic discussions allowing clients to embrace their experiences and feelings. *Active music therapy,* on the contrary, involves creative participation in music making, whether individually or in groups. Singing is often used because it can help patients with articulation and breath control, improve the oxygen saturation rate, and stimulate language. Playing instruments, in turn, can improve motor control; facilitate cooperation and attention; and enhance joint mobility, range of motion, rhythm, balance, strength, and self-esteem. In the Nordoff–Robbins approach, called *creative music therapy*, clients and therapists engage in a creative process of musical improvisation. Depending on their musical background, clients may be given instruments that are easy to make a sound with, such as simple percussion instruments, and are invited to improvise. As with receptive music therapy, the music experiences that arise during the therapeutic process can be used as a springboard for discussions, but many benefits arise spontaneously from engaging in an enjoyable activity that stimulates reward centres in the brain, promotes cooperation and a sense of accomplishment, and engages a range of cognitive–motor functions (Thaut 2005; Thaut et al. 2008; Thaut and Abiru 2010).

Music-based interventions are personalized according to the needs of the clients (e.g. according to their physical state and psychosocial needs). In this book, we describe research and practical implications of the effects of music-based interventions on people with different conditions. In the following chapters, we describe concrete applications and protocols for music interventions in diverse health contexts:

- *Cerebral palsy (Chap. 2)*. In the case of cerebral palsy, music therapy can help with motor development, socialization, and communication. Music therapy can also help improve cognitive abilities and overall quality of life.
- *Autism spectrum disorder (Chap. 3)*. For individuals with autism, music therapy can help improve communication, social skills, emotional regulation, and emotional recognition of others.
- *Stroke (Chap. 4)*. For stroke patients, music therapy can be a valuable part of their rehabilitation. Music therapy can help improve motor skills and coordination, as well as speech and language skills. It can also provide emotional support and help reduce anxiety and depression.
- *Emotional disorders (Chap. 5)*. In the case of depression and emotional disorders, music therapy can be an effective treatment. It can help reduce symptoms of depression and anxiety, improve mood, and increase overall well-being. Music therapy can also help individuals express themselves in a non-verbal way, which can be especially helpful for those who struggle with verbal communication.
- *Palliative care (Chap. 6)*. In palliative care, music therapy can be used to help patients cope with the physical and emotional challenges that come with end-of-life care. It can provide comfort and support, reduce anxiety and depression, and help patients and families process their emotions.

1.3 From Notes to Neurons

The effects of music on health can be analysed on several levels, from cognitive functions to emotional responses to changes in brain activity patterns. Music can alter brain functions because of the highly adaptable nature of our neural networks, known as brain plasticity. Brain plasticity can account for changes in the brain following music training or the effects of music therapy. With the advent of new neuroimaging studies, human responses to music are being viewed through a new lens. Neuroimaging research has significantly enhanced our comprehension of the neural underpinnings associated with various cognitive capacities, unlocking a new realm of knowledge about how music therapy may produce a profound impact by yielding substantial improvements across diverse medical conditions.

Among neuroimaging techniques, functional magnetic resonance imaging, also known as fMRI, is a powerful method for measuring brain activity by capturing changes linked to blood flow. This technique is based on the fundamental connection between cerebral blood flow and neuronal activation. When a specific brain area is engaged in a task or activity, there is a corresponding increase in blood flow to that region. Functional techniques, such as fMRI, have played a significant role in advancing cognitive neuroscience as they allow us to pinpoint the timing and location of neural activity in the brain associated with specific cognitive tasks. While fMRI (and other techniques such as near-infrared spectroscopy) indirectly measures neuronal activity by examining changes in local blood flow and metabolic activity, others directly measure electrical activity associated with neuronal firing. This is the case of electroencephalography (EEG) and magnetoencephalography (MEG). Electroencephalography (EEG), dating back to Berger's ground-breaking discovery in 1929, involves recording brain electrical activity through electrodes placed on the scalp. This technique remains highly valuable today due to its ability to provide real-time measurements of brain activity. EEG captures transient electrical dipoles generated by the flow of electrical current across cellular membranes during neuronal depolarization linked to postsynaptic potentials. EEG is utilized to assess neural activity across different brain states. A related approach in cognitive neuroscience is the utilization of event-related potentials, which entail averaging EEG activity over a series of trials triggered by the same event, such as the presentation of a visual stimulus.

While direct measures of neural activity, such as EEG, offer an exceptional temporal resolution, allowing for the detection of changes in neural activity at a millisecond level, they suffer from poor spatial resolution, making it challenging to precisely identify the source of the recorded signals. On the contrary, indirect measures of neural activity exhibit better spatial resolution compared to EEG, but they lack temporal precision. Hence, there exists a trade-off between high temporal accuracy and high spatial precision in neuroimaging. In addition, an fMRI scanner is significantly more expensive than EEG devices, and EEG devices are portable while fMRI scanners are not. With the recent appearance of low-cost EEG devices, EEG has become a very attractive technique for studying brain activity responses to all kinds of stimuli. In this book, we describe several studies in which EEG has been used to analyse, understand, and implement music interventions across a variety of contexts. These studies offer valuable insights into the intricate connection between music and the brain, laying the groundwork for the design and implementation of new powerful, accessible, and non-invasive music interventions.

1.4 Chapter Summary

In this chapter, we explored the connection between music and health, as well as the potential of utilizing music as a therapeutic tool to enhance the well-being and overall health of individuals facing various conditions. Additionally, we provided a short introduction to neuroimaging techniques and their pivotal role in advancing our understanding of the neural mechanisms underlying music's impact on health and well-being. These insights serve as a foundation for the development and implementation of innovative music interventions.

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Chapter 2
Accessible Digital Music Instruments for *Motor Disability*

Check for updates

Contents

2.1 Motor Disabilities

Motor disabilities represent a diverse set of conditions that affect an individual's movement capacity. These disorders can stem from a variety of causes, ranging from genetic predispositions to acquired injuries. They can influence an individual's mobility, coordination, strength, or even muscle tone, making it challenging to perform everyday tasks. There are different kinds of motor disabilities, some of them include:

R. Ramirez-Melendez, *Neurocognitive Music Therapy*,
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- Cerebral palsy: This group of disorders is caused by damage to a developing brain, usually before birth. Cerebral palsy primarily affects body movement, muscle control, coordination, and tone. Depending on the region of the brain affected, symptoms can range from mild to severe, including difficulty with precise movements such as writing or speaking to difficulty with controlling gross motor skills such as walking.
- Spinal cord injury: Damage to any part of the spinal cord can result in permanent changes in strength, sensation, and function below the site of the injury. Depending on the severity and location of the injury, this can lead to complete or incomplete paralysis.
- Muscular dystrophy: This is a group of genetic diseases characterized by progressive weakness and loss of muscle mass. The most common form in children, Duchenne muscular dystrophy, particularly affects boys and leads to difficulty in walking and general mobility.
- Multiple sclerosis: This is a potentially disabling disease of the brain and spinal cord in which the immune system attacks the protective sheath (myelin) covering nerve fibres. This results in communication problems between the brain and the rest of the body. Symptoms can include fatigue, difficulty walking, numbness or weakness, and lack of coordination.
- Amyotrophic lateral sclerosis (ALS): This is an uncommon neurodegenerative disorder that primarily targets motor neurons. These are specialized nerve cells residing within the brain and spinal cord that orchestrate voluntary muscle activities. Voluntary muscles cater to intentional movements integral to daily life such as walking and talking. As an inherently progressive disease, ALS amplifies its symptoms over time, gradually exacerbating the patient's condition.

Each of these motor disabilities has its unique characteristics and challenges. However, with the right combination of therapies and assistive technologies, individuals with motor disabilities can lead fulfilling lives, fully participating in their communities. Music therapy and assistive technologies such as digital music interfaces can play an important role in the management and treatment of motor disabilities. Music therapy employs the power of rhythm and melody to stimulate neural pathways involved in voluntary movement and coordination. This therapeutic approach can help to reinforce and augment existing motor functions, even in the face of degenerative conditions. Moreover, the rhythmic elements inherent in music can aid in establishing a regular movement pattern, improving gait and overall coordination. Besides its direct physiological benefits, music therapy may also provide an engaging platform for social interaction and emotional expression, as well as several benefits for acquiring non-musical skills (more on this in the next section). Consequently, it not only fosters motor improvement but also strengthens mental health, providing a holistic intervention for individuals suffering from motor disabilities.

2.2 Music Playing Benefits

Playing and learning to play a musical instrument have been shown to provide several benefits for acquiring non-musical skills (Coffman 2002). For instance, musicians have an improved ability to hear speech in noisy backgrounds (Parbery-Clark et al. 2009), reduced age-related auditory degradation (Parbery-Clark et al. 2011), increased verbal and auditory memory (Chan et al. 1998; Ho et al. 2003), and enhanced auditory attention (Strait et al. 2010). Music instrument training is associated with neurostructural changes (Wan and Schlaug 2010; Besson and Schön 2012) both in children (Hyde et al. 2009) and in adults (Bangert and Altenmüller 2003). Motor brain regions are enlarged in musicians when compared to non-musicians (Elbert et al. 1995). Grey matter volumes tend to be larger in musicians than in non-musicians for motor, auditory, and visual-spatial brain regions (Gaser and Schlaug 2003). Furthermore, grey matter density is greater in Broca's (language) area for trained musicians (Sluming et al. 2002). The corpus callosum, the fibres connecting the left and right hemispheres, was found to be larger in musicians compared to non-musicians (Schlaug et al. 1995). Musicians' resistance to age-related neural decline is greater for musicians when compared with non-musicians (Pagnoni and Cekic 2007). Early instrumental musical training seems to train attentional networks in the brain, as well as social and interpersonal skills. Children exposed to musical training show improvements in non-verbal memory, IQ, numeracy, and spatial cognition (Neville et al. 2008). However, due to a lack of fine motor skills, people with motor disabilities are often incapable of learning to play a musical instrument, and thus, the benefits of music training and playing are inaccessible to them. In this context, accessible digital musical interfaces (ADMIs) provide a possible alternative for allowing people with motor disabilities to enjoy music learning and playing, and their associated benefits.

2.3 Accessible Digital Music Interfaces

The concept of creating accessible digital music interfaces (ADMIs) for individuals with motor impairments has been around for some time. Different ADMIs have been suggested based on the specific motor challenges faced by individuals. Kirk et al. (1994) presented the MidiGrid and the MidiCreator. The MidiCreator can be connected to a variety of sensors, such as an ultrasonic distance sensor or a pressure-sensing foam. Through the midiGrid interface, the user can assign different music events to the messages sent by the MidiCreator. The system has been used in education and music therapy settings. Skoog[1] is a low-cost pressure and deformation-sensitive cube. It has served as a musical instrument for people with cerebral palsy. Another example of a tangible musical interface is TouchTone,

[1] https://skoogmusic.com, last accessed on 22/06/2023.

proposed by Bhat (2010). It consists of ten keys arranged in two rows. The arrangement and size of the buttons make the interface accessible to users with limited fine motor movements. Swingler (1998) introduced the Soundbeam. The input is provided by an ultrasonic distance sensor that is accompanied by buttons adapted to the needs of the user. The distance from the sensor along with the direction and speed of the part of the body that serves as the input is converted to midi data. Soundbeam is a commercial product. Webcamera-based low-cost systems are widely used (Winkler 1997; Lamont et al. 2000; Stoykov and Corcos 2006; Oliveros et al. 2011). Typically, the screen is separated into distinct areas, and when a movement is detected in each area, an event is triggered. All the interfaces mentioned above are designed for people who preserve a degree of limb movement. For people without adequate control of limb movements, an interface such as the Magic Flute 2 might be more appropriate. It is a head and breath–controlled digital musical interface. The volume is controlled by blowing in a mouthpiece and the pitch by moving the mouthpiece up/down with the mouth.

In more severe cases of motor disabilities, such as people with severe cerebral palsy or with locked-in syndrome (LIS), none of the mentioned interfaces is appropriate. In these situations, while patients retain their cognitive functions, their ability to move or verbally communicate is hindered due to either limited control or total paralysis of almost all voluntary muscles, with the exception of those that control eye movements. (Bauer et al. 1979; Smith and Delargy 2005). In such cases, communication through eye-tracking technology might be the only alternative.

In this chapter, we present accessible digital music interfaces as a means to empower those with motor disabilities, such as individuals with cerebral palsy, to learn, play, and create music, tapping into the benefits it offers. We specifically highlight the EyeHarp, a gaze-operated accessible digital musical instrument. This tool enables individuals with significant motor impairments to learn, expressively perform, and compose music by utilizing their gaze as the primary control mechanism. Drawing from our past experiences, we suggest a method to employ the EyeHarp for promoting music making and improving the well-being of those with severe motor challenges.

2.4 Gaze-Based Digital Music Interfaces

In interfaces that utilize eye tracking or gaze-controlled methods, the gaze data can be used independently or alongside other input techniques, such as controls operated by the head, limbs, or even breath. Actions can also be triggered using blinks, involving either both eyes or a wink using just one eye. Typically, gaze coordinates function for pointing purposes, while other inputs initiate specific actions. When relying solely on gaze input, interpreting this data requires precision due to the frequent unintentional movements of the eyes. This challenge in distinguishing intentional from unintentional gazes is known as the "Midas Touch" problem.

Two prevalent gaze selection techniques designed to address the Midas Touch issue are:

1. The screen button method, introduced by Ohno (1998), divides the screen into a command name area and a selection zone. Only the targets in the command area activate commands.
2. The dwell-time method, proposed by Jacob (1991), determines a selection when a gaze remains fixed on a target for a predefined duration, usually around 1 s.

Hornof (2014) conducted a comprehensive review of music performance systems controlled by eye movements. Notably, some of these systems do not aim to emulate traditional musical instruments. Instead, they might be better characterized as sonifications of eye movements, and they are not tailored for melodic performances. When we discuss digital music instruments in this context, we are referring to platforms that facilitate the playing of distinct notes. One such platform is the Grid software,[2] which uses a dwell-time selection mechanism via a Tobii eye tracker[3] to activate predetermined sounds. A more recent endeavour titled "Eye play the piano",[4] a collaboration between the University of Tsukuba and the FOVE eye-tracking virtual reality headset,[5] enables individuals with disabilities to initiate piano notes or chords. These are mapped to on-screen buttons, with blinking serving as the selection technique.

In the gaze-controlled systems mentioned, both dwell-time and blinking methods are employed to instigate musical events. However, each has its drawbacks. The dwell-time method, due to inherent latency, is unsuitable for on-beat event triggering. Blinking, on the other hand, necessitates two distinct actions to trigger a single event: first focusing on a target and then blinking. It is also worth noting that none of these systems offer the capability to manipulate more expressive musical parameters, such as loudness.

The EyeHarp is an interface which uses only the gaze as input. An analogy with traditional instruments would be a piano in which a sound is triggered by the sole action of looking at the corresponding key. The EyeHarp uses the screen button gaze selection method and allows the control of chords, arpeggios, melody, and loudness using only the gaze as input. In a research conducted by Vamvakousis and Ramirez (Vamvakousis and Ramirez 2012), the expressive capabilities of the EyeHarp were assessed, considering both the performer's and audience's perspectives. The findings revealed that the EyeHarp offers musicality and expressiveness on par with conventional musical instruments.

[2] http://sensorysoftware.com, last accessed on 22/06/2023.

[3] http://www.tobii.com, last accessed on 22/06/2023.

[4] http://eyeplaythepiano.com/en, last accessed on 22/06/2023.

[5] https://wearables.com/products/fove-vr-headset, last accessed on 22/06/2023.

2.5 The EyeHarp

The EyeHarp (theeyeharp.org) is a free accessible digital music instrument which allows the user to control the pitch, timing, and dynamics of a melody, as well as chords and arpeggios in a performance. Its interface consists of two layers: the step sequencer layer and the melody layer. In the step sequencer layer, chords and arpeggios can be constructed, and in the melody layer, these can be controlled and a melody can be played. The number of available note buttons can be adapted according to the accuracy of the eye tracker and the expertise of the performer. The user can switch between the two layers through a dwell-time activated button.

The EyeHarp has a built-in analogue software synthesizer, and it also works as a MIDI device, controlling any external software synthesizer. The EyeHarp currently supports several commercial eye trackers. Fixation detection and smoothing algorithms are incorporated into the EyeHarp software. This allows a consistent behaviour of the system when different eye trackers are used. The interface is diatonic and by default tuned to the C major scale. Nevertheless, it is easily configured to play any possible scale, including microtonal non-western scales. A detailed overview of the more advanced features of the interface was presented by Vamvakousis and Ramirez (2011).

2.5.1 The Step Sequencer Layer

Figure 2.1 shows the step sequencer layer. A step sequencer is an interface for constructing loops. It consists of a grid of buttons where the vertical dimension of the grid corresponds to pitch and the horizontal dimension corresponds to the temporal position in the loop. At the beginning of the loop, the selected notes of the first column sound simultaneously, followed by the selected notes of the second column, and so on. After the notes of the last column are played, the loop starts over. The time interval between the activation of two consecutive columns is constant and depends on the set tempo.

To select a button on the step sequencer, the dwell-time selection technique is employed. The EyeHarp interface comes with a default dwell time of 700 ms. Each button is represented as a circle, with a distinct focus point situated at its centre. This central focus point aids users in directing their gaze precisely at the target's centre, thereby enhancing the accuracy of the tracking data, as noted by Kumar et al. (2008).

The step sequencer layer incorporates two strategies to further refine the spatial accuracy of the eye tracker, illustrated in Fig. 2.2. The first strategy displays the gaze point on the screen and is accompanied by supplementary focus points located on the buttons' periphery. This assists users in adjusting for any discrepancies resulting from imprecise tracking, a technique reminiscent of the one proposed by Kumar et al. (2008). In the second strategy, once fixation is registered and the

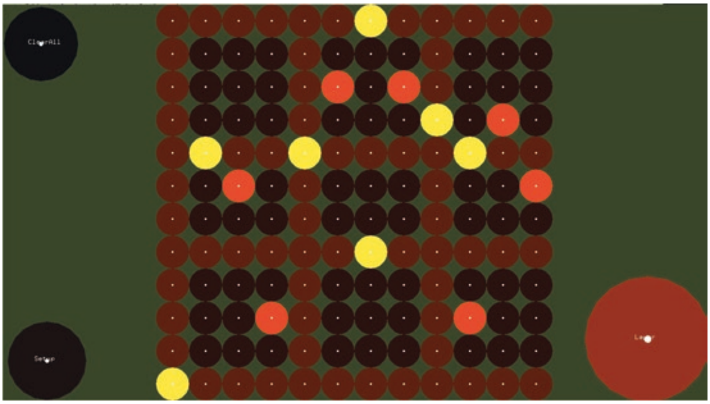

Fig. 2.1 The step sequencer layer. In this layer, the user can construct arpeggios and chords which are controlled in the melody layer. Buttons in the same row correspond to notes with the same pitch, while buttons in the same column correspond to simultaneous notes. If the selected chord in the melody layer is C major, buttons from bottom to top correspond to notes C4, D4, E4, etc. Notes are triggered from left to right, starting with the leftmost column. The dwell-time selection method is used, i.e. users focus on each button for about 700 ms in order to select or release a button

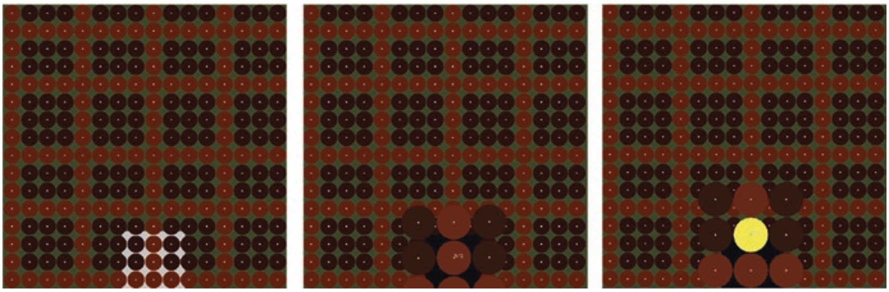

Fig. 2.2 The magnification method for improving spatial selection accuracy. If the magnified area appears outside the screen, it smoothly moves inside

designated dwell-time duration elapses, any step sequencer buttons that lie within a square region – centred on the fixation point and spanning 20% of the sequencer's area – are enlarged by a factor of two. Users can then choose from these enlarged buttons. By directing their gaze beyond this magnified section, the buttons revert to their original dimensions and placement.

The step sequencer layer is a layer for constructing arpeggios, whose harmony is controlled in the melody layer. The note that corresponds to the bottom row of the EyeHarp's step sequencer is determined by the base note of the selected chord in the melody layer. The notes corresponding to the other rows in the step sequencer are mapped to the consecutive notes. For example, if the EyeHarp is tuned to the C major scale and the selected chord in the melody layer is the tonic (C major), the buttons of the first row correspond to the note c in the third octave. The buttons in the second row correspond to the note D, and so on. In case the selected chord is the dominant (G Major), the first row is mapped to the note g in the third octave, the second to a, and so on.

2.5.2 The Melody Layer

The melody layer, depicted in Fig. 2.3, employs a design based on pie menus. Such a menu is segmented into various “pie slices”. Each slice is characterized by an inactive zone in its centre and an active selection zone lining the outer circumference. The concept of integrating pie menus within gaze interactions was pioneered by Huckauf and Urbina (2008) for applications in typing and desktop navigation. The pEYE layout design is particularly conducive to melody play, as it eliminates the need for actual clicking to register a selection. Merely navigating the pointer into the outer selection zone of the pie instantly activates a command.

In essence, the pie menu slices in the melody layer can be equated to screen buttons, an idea put forth by Ohno in 1998. For every note and chord, the designated command area displays a respective numeric and Latin numeral. The selection zone of these commands is strategically positioned at the pie’s edge. Within each note’s selection boundary lies a central focus point. As an additional feature, illustrated in Fig. 2.4, each slice’s selection area can potentially house multiple focus points. Those positioned towards the outer edge correlate with heightened loudness and vibrato, whereas inner points are associated with diminished loudness and vibrato.

If the set scale is C major, c in the fourth octave is placed at 180°. The scale then goes up anticlockwise. As a default option, the pie comes with 14 slices, but the number of slices can be adapted through the setup menu. If the setup button is pressed in the melody layer, a number of configuration buttons appear. Two repeat buttons on the left can be used to adjust the number of notes in the pie. Through four radio buttons on the top, the user can select between three preset sounds of the EyeHarp internal synthesizer, or select the midi out option. In that case, the interface sends MIDI messages to an external synthesizer.

If the “chords” button is active, the last six notes of the pie are replaced by six chords. These buttons control the harmony of the arpeggio constructed in the step sequencer layer as explained in Sect. 2.5.1. In order to play a note or change the chord, the user can either look directly at the selection area of the note/chord or – in case there is a big distance on the screen between two consecutive notes – they can focus on the command name area before focusing on the selection area. This is expected to improve spatial and temporal accuracy, as Fitt’s law also applies to gaze interaction as shown by Miniotas (2000).

In order to release a note, the user has to look at any place outside the pie. For that reason, fixation points are placed outside the pie. When a fixation is detected at the selection area of a note, the note sounds and a button appears at the centre of the pie. This allows the user to repeat the same note twice. If a fixation is detected inside the button’s area, the same note sounds again. If a fixation is detected elsewhere inside the inner (neutral) area, the “repeat” button disappears.

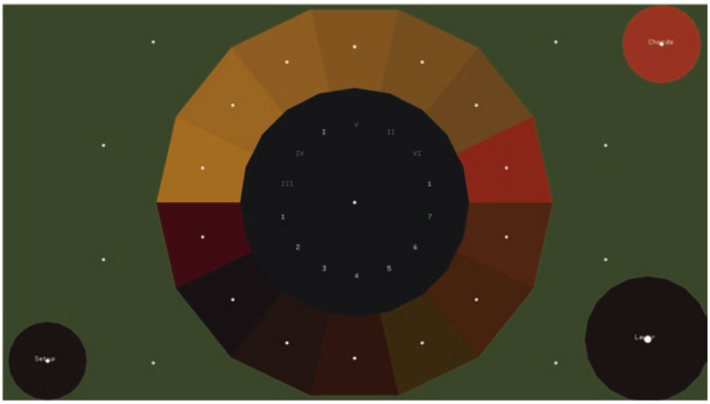

Fig. 2.3 The melody layer is where the user plays melodies and changes the chords/arpeggios constructed in the step sequencer layer. The melody layer buttons are placed over the perimeter of a circle, leaving the area in the centre inactive

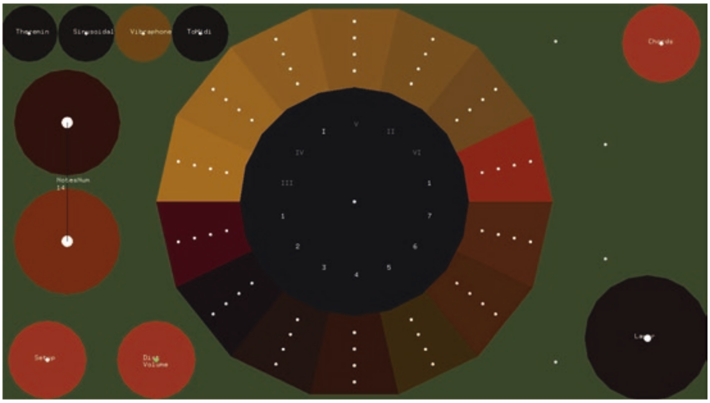

Fig. 2.4 By activating the "setup" button through dwell time, the user can change various parameters of the interface including the "dynamics" button which allows to map the distance from the centre of the "pie" to the loudness of the performed note

2.5.3 The EyeHarp as a Music Instrument

O'Modhrain (O'Modhrain 2011) suggested that digital music interfaces (DMIs) can be assessed through various perspectives, such as the viewpoint of the audience or the performer. In this section, we delve into the assessment of the EyeHarp from an audience's perspective.

Transparency refers to how easily a performer or observer can discern the connection between input actions (gestures) and the resulting output (sound). Hunt et al. (2002) and Arfib et al. (2005) contend that the clearer this connection, or the instrument's transparency, the more expressively it can be played. This means there is a direct relationship between the performer's motions and the sounds generated by the instrument. However, with DMIs, the link between the performer's movements and the ensuing sound might not always be overtly apparent to spectators. Schloss (2002) suggests that when this cause-and-effect relationship is obscured, it alters the audience's perception of the performance. According to Schloss, providing visual cues that aim to reestablish the connection between cause and effect is a key component in making a DMI performance convincing and effective.

Reeves et al. (2005) proposed an evaluation of DMIs based on audiences' perception of the relationship between input manipulations and audio output. They characterize a performance with low input and output comprehension as "secretive," one with low input and high output comprehension as "magical," one with high input and low output as "suspenseful," and one with high input and output as "expressive." Barbosa and Calegario (2012) extended Reeves's classification and proposed five different aspects to be considered in building the "interaction model" of a DMI:

- The cause comprehension refers to how clear the available input gestures are.
- The effect comprehension refers to how clear the controlled parameters are.
- The mapping comprehension refers to how clear is the relationship between the user's actions and the resulting sound.
- The intention comprehension refers to what degree the system allows the user to express his musical intentions.
- Error comprehension refers to whether the possible errors in the performance were noticeable.

To assess the EyeHarp's capabilities as a musical instrument, we staged a concert at Universitat Pompeu Fabra's concert hall. The musician, who had trained on the EyeHarp for 10 weeks – practising thrice a week for roughly 20 min each time – offered a two-part performance. Initially, he presented a solo piece he composed specifically for the EyeHarp. Subsequently, he joined a trio comprising two guitarists and a flutist for a jam session. During the performance, one of the performer's eyes was projected centrally on a screen, with a small cross indicating his gaze coordinates.

This performance was then recorded and made available online (https://youtu.be/dS5QkIgK0NY). We showcased this recording to a group of 31 people, none of whom had prior knowledge of the EyeHarp. All participants possessed, at minimum, a basic proficiency in playing a musical instrument. Post-viewing, the participants completed a survey. This questionnaire captured the demographic details of the participants (such as age, gender, musical training, familiarity with DMIs, and eye-tracking technology) and delved into the evaluation criteria as suggested by Barbosa and Calegario (2012). Responses were recorded on a linear scale ranging from 1 to 5. The 31 respondents (including 6 women) had an average age of 30.5 years with a standard deviation of 5.8. They addressed questions spanning six evaluation criteria:

1. Cause comprehension: Were the available input gestures clear? (1: not at all; 5: very clear).

2. Effect comprehension: Were the available control parameters clear? (1: not at all; 5: very clear).
3. Mapping comprehension: Was the connection between the input gestures and the control parameters clear? (1: not at all; 5: very clear).
4. Intention comprehension: How well did the system allow the user to express his musical intentions? (1: not at all; 5: very well).
5. Error comprehension: If there had been errors in the performance, would they have been noticeable? (1: not at all; 5: very noticeable).
6. Enjoyment: How much did you enjoy the performance? (1: not at all; 5: a lot).

Figure 2.5 shows the average responses and the corresponding standard deviation across all participants. The responses of the audience can be summarized as follows: The available input gestures were clear (average = 3.9, σ = 0.87). The available control parameters were clear (average = 3.8, σ = 1.04). The connection between them was clear (average = 3.7, σ = 1.34). The system allowed the user to express his musical intention very well (average = 4.2, σ = 0.76). Errors in the performance would have been noticeable (average = 3.1, σ = 1.06). Finally, the audience enjoyed the performance a lot (average = 4.3, σ = 0.84).

Based on feedback from the audience, the EyeHarp demonstrates a clear relationship between the input gestures and the resulting sound. On average, participants rated their understanding of the action (cause comprehension), the outcome (effect comprehension), and the connection between gesture and sound (mapping comprehension) at above 3.5 on a 5-point scale (refer to Fig. 2.5). This suggests the musical instrument's design is transparent and easy to understand in terms of its operations and the associated sound outcomes. As pointed out by Hunt et al. (2002) and Arfib et al. (2005), these characteristics (transparency and comprehensibility) can enhance an instrument's potential for expressive performances and audience

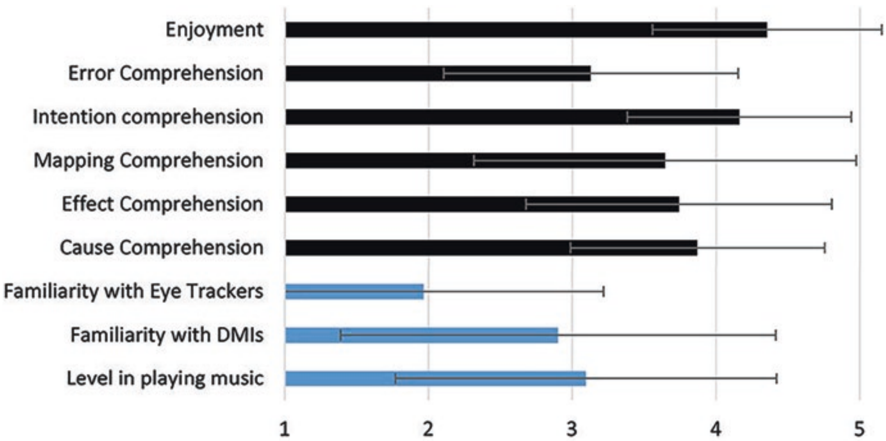

Fig. 2.5 Qualitative evaluation average results from the audience perspective across 31 participants. In blue appear the questions related to the profile of the audience and in black the questions related to the evaluation of the DMI

engagement. However, the standard deviation for the gesture–sound relationship evaluation was 1.33, hinting that some attendees might not have grasped this connection entirely. The standard deviation was less for understanding cause and effect. Although the EyeHarp is primarily a diatonic DMI, producing seldom dissonant notes, the audience rated their grasp of errors highly, with an average score of 3.1. This further emphasizes their understanding of the link between the performer's moves and the ensuing music. Every audience member expressed enjoyment of the performance, averaging a 4.3 rating out of 5. The majority felt that the interface effectively conveyed the musician's intentions, with an average score of 4.2 out of 5, suggesting the EyeHarp's potential for expressive musical performances.

2.6 The EyeHarp as a Therapeutic Tool for Motor Disabilities

The EyeHarp has played a central role in projects aiming to make music accessible to people with motor disabilities. An example of these projects is MUSA (accessible music to break down invisible barriers), a collaboration project between PHONOS, the Music and Machine Learning Lab, the Music Technology Group, and the Escola Superior de Música de Catalunya (ESMUC), which received the support of Obra Social la Caixa within his Art for Change programme. The MUSA project aimed to promote and democratize musical learning and practice among those people who have some kind of motor difficulty that prevents them from playing traditional musical instruments. This goal was achieved through the use of the EyeHarp. The MUSA project ended with a final concert (a fragment of which is available online at https://www.youtube.com/watch?v=L7k6zkGKkVg) in which digitally adapted and traditional instruments coexisted to interpret a repertoire in an act open to the public. The main objectives of MUSA were:

- Allow people with motor disabilities access to learn, perform, improvise, and compose music with other musicians using adapted digital music interfaces, in particular the EyeHarp.
- Offer regular musical training and musical practice to people with motor disabilities.
- Create sustainable music ensembles consisting of people with and without motor disabilities playing the EyeHarp along with traditional musical instruments.
- Better understand the needs of people with motor disabilities in order to improve music technology capabilities.
- Make the EyeHarp accessible to an increasing number of people.
- Offer training and resources to entities that work with people with motor disabilities so that they can continue independent training with users over time.

The participants of MUSA were people with limited mobility not able to play music with traditional instruments. In particular, conditions among participants included cerebral palsy, amyotrophic lateral sclerosis, and paraplegia.

The MUSA project was developed in different phases:

1. *Contact with entities and users.* The first phase of the MUSA project was to establish collaborations with different entities which work with groups of people with physical disabilities to find the participants for the project.
2. *Training of participants with the EyeHarp.* MUSA organized regular (weekly) training sessions with the participants where the technologies (i.e. the EyeHarp and other digital music interfaces) were presented. The sessions played the role of music lessons in which basic music theory was introduced, and participants learned to play and improvise with the EyeHarp. The pieces were chosen by the participants and were planned to be performed later in the project with other musicians playing traditional musical instruments.
3. *Research, test with users, and improvement of the software.* Through the direct relationship of the participants during the weekly sessions with the EyeHarp, tests and technical improvements were carried out to improve and adapt the EyeHarp to participants' needs. Different motion capture sensors were tested, and minor extensions to the user interface were made to optimize the participants' experience.
4. *Music ensemble rehearsals.* Rehearsals of musical ensembles with both traditional and accessible instruments were interleaved with the training sessions. These musical ensembles consisting of EyeHarp players and conservatoire music students performed different repertoires and combined the use of traditional instruments with adapted digital instruments. Videos illustrating the rehearsal process are available at: https://www.youtube.com/playlist?list=PLcxXGgI4zIjGyr90vCtaQO34ca2FKvMHg.
5. *Relevant institutions training.* The project provided training to entities and associations which work with people with motor disabilities. Face-to-face training sessions were organized, and software and teaching materials were provided: The EyeHarp was freely provided to the institutions as well as technical manuals for using and learning to play music. Basic notions for music playing with the EyeHarp were given.

2.6.1 Implications

One of the main outcomes of the EyeHarp through projects such as MUSA is the empowerment of people with motor disabilities through music learning and performance, creativity and participation in culture. Making available digital music instruments such as the EyeHarp to the motor disability community allows access to music learning, composition, and performance, and thus to music's many benefits, for instance, reduced auditory degradation and increased verbal memory. Of particular importance is the social aspect that music provides, which is extremely relevant for people with motor disabilities whose social interactions are often limited. The EyeHarp becomes an accessible instrument to enjoy a musically active life, just as the piano, guitar, or violin is for people without motor disabilities.

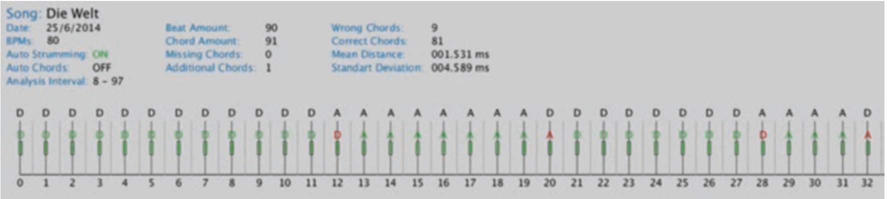

Fig. 2.6 Representative pitch accuracy example. BPM: 80; auto-timing: on; auto-pitch: off; number of target notes: 33; missing notes: 0; correct notes: 29; wrong notes: 4; note accuracy: 0.88

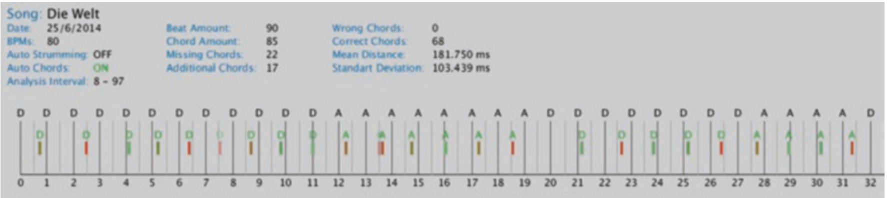

Fig. 2.7 Representative timing accuracy example. BPM: 80; auto-timing: off; auto-pitch: on; number of target notes: 33; missing notes: 9; correct notes: 24; wrong notes: 0; note accuracy: 0.73; mean distance: 181.75 ms; standard deviation: 105.4 ms

Not surprisingly, the learning curve of people with motor disabilities for playing music with digital instruments such as the EyeHarp is similar to that of people without motor disabilities for learning traditional instruments. However, one aspect of music playing which is initially particularly challenging for users who are not able to walk and do not have speech is maintaining the tempo/rhythm, i.e. playing on time. Understandably, not having the benefit of daily activities which are intrinsically rhythmical such as walking and speaking has an impact on tempo/rhythm processing. Figures 2.6 and 2.7 show a representative performance for pitch and rhythm tasks, respectively, of a beginner student. Typically, when timing accuracy is not part of the task, this is when note timings are controlled automatically, a beginner student will accurately perform most of the notes (Fig. 2.6). However, when timing accuracy is part of the task and pitch is not part of it, a beginner student will have difficulties playing the notes on time (Fig. 2.7). Taking this into account and based on the experience with users, tools and exercises have been developed in the EyeHarp to specifically train tempo/rhythm skills. The system can be configured to display a timing aid in the form of a circle indicating the duration of notes: Note onsets are specified by a full circle, and the circle is gradually consumed until the offset of the note. This aid is normally used for initially practising music pieces, and it is removed when the student has mastered the piece timing, just as musicians use scores to initially practice music pieces. Figure 2.8 shows an EyeHarp student practising a song using the timing aid tool. On top of the note being performed, a purple partial circle is displayed indicating the remaining note duration.

One of the transformative impacts of the EyeHarp is its empowerment of individuals with motor disabilities, granting them self-sufficiency in musical practice.

Fig. 2.8 An EyeHarp student practising a song with the timing aid tool. The gradually consuming purple circle on top of the performed note indicates the reminder duration of the note

Many of these individuals already employ eye-tracking or head-tracking technologies in their daily interactions, making the transition to EyeHarp seamless. This inherent familiarity lets them delve directly into the nuances of music, rather than navigating the technology. Moreover, initiatives such as the MUSA project champion the seamless inclusion of those with motor disabilities in consistent musical training and foster their active participation in musical groups. The MUSA project not only showcased the myriad opportunities that modern technology brings to music education but also played a pivotal role in its widespread adoption. Presently, the EyeHarp is as mainstream as traditional instruments in two Spanish public music schools. Its introduction has also inspired numerous institutions catering to those with motor disabilities to integrate it into their programmes.

The global presence of the EyeHarp, demonstrated through concerts worldwide, has been instrumental in augmenting the recognition of individuals with motor disabilities in the musical world, highlighting their capacity to contribute meaningfully to the realm of musical creation.

2.7 Protocol: Music-Based Intervention for People with Motor Disabilities

2.7.1 Objective

The objective of this music-based intervention is to provide people with severe motor disabilities the opportunity to learn, perform, and compose music with other musicians using accessible digital music interfaces, in particular, the EyeHarp. In doing so, these individuals can tap into the many benefits that music offers. Whether it is cognitive stimulation, emotional expression, or fostering social connections, the embrace of music can significantly enhance their quality of life and well-being. By integrating technologies such as the EyeHarp, we not only facilitate the inclusion of those with motor disabilities in the musical landscape but also open doors for them to experience the holistic benefits of musical engagement.

The protocol aims to create sustainable music ensembles consisting of people with and without motor disabilities playing the EyeHarp along with traditional musical instruments, offer regular musical training and musical practice to people with motor disabilities, better understand the needs of people with motor disabilities in order to improve music interventions, make music playing even more accessible to everyone, and offer training and resources to entities that work with people with motor disabilities so that they can continue independent training with users over time.

2.7.2 Participants

The participants of this music-based intervention are people with severe motor disabilities who are not able to play music with traditional instruments, including those with cerebral palsy, amyotrophic lateral sclerosis, and paraplegia.

2.7.3 Phases

(a) Contact with entities and users:

The first phase of the intervention is to establish collaborations with different entities which work with groups of people with physical disabilities to find the participants of the project. The inclusion criteria for participants are as follows:

- Interest and willingness to learn to play music.
- Ability to control the direction of gaze with reasonable accuracy and precision.
- No significant vision impairments or eye conditions that would affect gaze control.
- Adequate cognitive abilities to follow simple instructions related to music learning.
- Normal hearing ability to perceive and understand musical sounds.
- Willingness to engage and interact with other music players in the learning process.

(b) Training of participants with the EyeHarp:

Organize regular (weekly) training sessions with the participants where they practise with the EyeHarp (and possibly other digital music interfaces). The sessions will play the role of music lessons in which basic music theory will be introduced, and participants will learn to play and improvise with the EyeHarp. As a starting point for the improvisation sessions, the EyeHarp can be configured to play pentatonic scales which can facilitate the sessions. The pieces will be chosen by the participants and will be planned to be performed later in the project with other musicians playing traditional musical instruments.

(c) Adaptation and personalization of the sessions:

Through the direct relationship of the participants during the weekly sessions with the EyeHarp, different training strategies will be carried out to improve and adapt the sessions to participants' needs. In the case of group sessions, both individual and group activities will be carried out.

(d) Music ensemble rehearsals:

Once participants have acquired basic music-playing skills, rehearsals of musical ensembles with traditional and accessible instruments will be interleaved with the training sessions. These musical ensembles consisting of EyeHarp players and music students or music therapists will perform different repertoires and combine the use of traditional instruments with digital music instruments.

(e) Relevant institutions training:

If possible, training for entities and associations which work with people with motor disabilities should be provided. This will greatly contribute to the sustainability in time of the music activities. Face-to-face training sessions will be organized and technical training will be provided: The EyeHarp will be freely provided to the institutions as well as instructions for using and learning to play music with the EyeHarp.

(f) Final concert:

A final concert involving all project participants should be organized. This, in addition to providing a common goal during the whole learning process, would allow project participants to showcase what they have learnt and share it with family, friends, and the community.

The described music-based intervention protocol provides people with motor disabilities the opportunity to access the benefits of playing and learning music through the use of accessible digital music interfaces such as the EyeHarp. The protocol aims to create sustainable music ensembles, offer regular musical training and practice, improve music technology capabilities, and make music accessible to everyone regardless of their physical abilities.

2.8 Chapter Summary

Playing a musical instrument has been widely known to have numerous benefits in acquiring various non-musical skills. Unfortunately, these advantages are not accessible to individuals with motor disabilities. However, accessible digital music interfaces can be an excellent solution for allowing people with motor disabilities to learn and play music, thereby providing them with the same benefits. One of these interfaces is the EyeHarp, a free-access gaze-controlled accessible digital musical instrument that enables individuals with severe motor disabilities to learn, perform, and compose music using their gaze as a control mechanism. The EyeHarp has played a pivotal role in providing access to music for people with motor disabilities. One of the main outcomes of the EyeHarp through projects such as the one described in this chapter is the empowerment of people with motor disabilities through music learning and performance, creativity and participation in culture. Of particular importance is the social aspect that music provides, which is extremely relevant for people with motor disabilities whose social interactions are often limited. Based on our experience, we describe a music-based protocol to promote music playing by making available digital music instruments such as the EyeHarp to individuals with severe motor disabilities.

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Chapter 3
Music as a Tool for Improving Emotion Identification in Autistic Children

Contents

3.1 Autism, Emotions, and Music

Autism spectrum disorder (ASD) is a neurodevelopmental condition influencing interpersonal interactions and behaviour. Its signs typically manifest within the initial 2 years of life. Those diagnosed with ASD, including those with high-functioning ASD, often encounter challenges in discerning and empathizing with others' mental states, such as emotions or intentions (Fitch 2005). Consequently, the disorder is frequently marked by impediments in social and communicative interactions (APA 2013). Extensive research indicates that individuals with ASD face challenges in recognizing emotions through facial cues (Celani et al. 1999; Boucher and Lewis 1992; Philip et al. 2010; Baron-Cohen et al. 2000), affective speech patterns (Lindner and Rosén 2006; Mazefsky and Oswald 2007; Golan et al. 2007; Philip et al. 2010), non-verbal vocal expressions (Hobson 1986; Heaton et al. 2012), and bodily gestures (Hubert et al. 2007; Hadjikhani et al. 2009; Philip et al. 2010). Moreover, abnormalities in brain activity patterns have been identified in ASD

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individuals in contrast to neurotypical counterparts. For instance, those with ASD often display diminished activity in the fusiform gyrus and amygdala when interpreting emotional facial expressions (Schultz et al. 2000; Critchley et al. 2000; Ashwin et al. 2007; Corbett et al. 2009) and atypical activation in the superior temporal and inferior frontal gyrus during auditory processing of speech (Gervais et al. 2004; Eigsti et al. 2012; Wang et al. 2007; Eyler et al. 2012).

People with ASD often enjoy music listening, are affected emotionally by music, and are usually musically talented (Kanner 1943). Previous studies have shown that individuals with ASD process melodic information (i.e. contour and intervals) in the same way as neurotypical people (Heaton 2005), and that they are better at pitch processing (Bonnel et al. 1999; Heaton et al. 1999; Heaton 2003) and show superior pitch memory (Stanutz et al. 2014; Heaton 2003). Notably, studies have also shown that individuals with ASD can correctly identify emotions in music just as well as neurotypical individuals (Allen et al. 2009a, b; Heaton et al. 2008; Quintin et al. 2011; Caria et al. 2011). Previous studies have found that ASD individuals listen to music as often as people without ASD because they feel emotionally affected by it (Allen et al. 2009b). Furthermore, it has been shown that the physiological responses to music in ASD individuals are the same as for neurotypical people (Allen et al. 2013), and previous work has observed preserved neural activity for music processing in children with ASD (Sharda et al. 2015). ASD individuals recruit brain regions involved in processing emotion and reward when they listen to happy and sad music, in the same way as neurotypical people do (Caria et al. 2011).

Music therapy (MT) harnesses the therapeutic power of melodies, rhythms, and movement and has been demonstrated to offer benefits in addressing certain medical and psychological challenges (Thaut et al. 2015; Geretsegger et al. 2014). Therapists have attempted to take advantage of the musical sensitivity and abilities of ASD individuals to compensate for the social interaction deficits (Alvin and Warwick 1992; Alvin 1978; Vaiouli et al. 2015). Despite MT being widely used for treating neurological and cognitive disorders (Paul et al. 2012; Wan et al. 2010), its application and evaluation for improving social skills in ASD (Molnar-Szakacs and Heaton 2012; Kaplan and Steele 2005) remain an open research area. Most of the research on using music as an intervention for ASD has centred on communication behaviours (Duffy and Fuller 2000; Finnigan and Starr 2010). For instance, Wan et al. (2011) proposed a music intervention based on auditory–motor mapping to improve language development in ASD children with no speech.

There have been several approaches to investigate the influence of music with affective content on individuals with ASD's ability to identify emotions depicted in visual stimuli.

Brown (2016) asked 30 neurotypical children and 20 children with high-functioning ASD to rate expressions (using a 7-point, very sad–very happy) scale of happy, neutral, and sad facial photographs while listening to sad music and happy music. Ratings of happy and neutral faces were unaffected by music conditions, but sad faces were perceived to be sadder with sad music than with happy music. Neurotypical children rated the happy faces as happier and the sad faces as sadder than did participants with ASD. Eren (2016) aimed to investigate the effect of music therapy interventions on teaching the facial expression of sadness to children with ASD. However, the study's main limitation was that it was conducted with only one participant. Black et al. (2017) conducted a systematic review of studies investigating the challenges of facial emotion recognition in ASD using eye tracking or EEG. The review indicated a divergence of visual processing pathways in individuals with ASD reflected in observable differences in eye tracking and EEG patterns. De Bruyn et al. (2011) conducted a qualitative study testing the musical empathic ability of participants with an autism spectrum disorder. Their results suggest that people with ASD can mirror the structural and affective features of music, concluding that they have an understanding of the affective features of music. Katagiri (2009) examined the effect of background music and song texts to teach the emotional understanding of happiness, sadness, anger, and fear to children with autism. Results showed that participants improved significantly in their understanding of the four selected emotions, with background music significantly more effective than other conditions.

In this chapter, we present a study exploring the potential usefulness of music as a tool for improving ASD children's emotion recognition in facial expressions and propose a protocol to apply its results in music interventions. In the study, children with ASD were exposed to facial expressions for four emotions (happiness, sadness, anger, and fear) with and without emotion-matching background music. EEG data were acquired during the four sessions, and instantaneous arousal and valence values were extracted from the EEG data. Inter- and intra-session emotion identification improvement was measured in terms of both verbal response accuracy and EEG response activity. Comparison of verbal responses in the first and last session showed a significant improvement, and the arousal/valence values computed from the participants' EEG data were highly correlated with the presented visual stimuli in the last session when compared to the first session.

3.2 Research: Music-Enhanced Emotion Identification of Facial Emotions in ASD Children

3.2.1 Participants

Participants included in this study were 25 children aged 6–11 years (all male, M = 8.8 y, SD = 1.2) with high-functioning autistic spectrum disorder (ASD) attending C.E.E. Carrilet and the Music Therapy Catalan Institute, Barcelona. The diagnosis of ASD was performed by an experienced clinician on the basis of DSM-V criteria, children's current situation, and developmental history. Diagnoses were confirmed using the Autism Diagnostic Observation Schedule (Lord et al. 2000). Global intelligence was measured using either the Wechsler Intelligence Scale for Children–Fourth Edition (Wechsler 2006) or the Wechsler Non-Verbal Scale of Ability (WNV) (Wechsler Naglieri 2011) depending on children's verbal abilities

(IQ $\geq$ 80). Children with psychiatric disorders were not considered. Written informed consent was obtained from the parents of the participants, and the study procedures were positively evaluated by the Clinical Research Ethical Committee of the Fundació Unio Catalana Hospitals, Barcelona, Spain, under reference number CEIC 15/55.

3.2.2 Materials

Facial Expression Database

The images employed in the three experimental conditions were drawn from the Karolinska Directed Emotional Faces database (1998) created at the Department of Clinical Neuroscience, Karolinska Institutet Stockholm, Sweden. These pictures are intended as a tool for medical and psychological purposes related to perception, emotion, and memory. Facial expressions were taken from five different angles with uniform light and position of participants' eyes and mouths. Participants were 70 volunteers equally clothed, 35 females and 35 males, ages ranging from 20 to 30 years. They displayed a total of seven different emotions (i.e. disgust, happiness, sadness, fear, anger, neutral, and surprise) which resulted in a set of 4.900 pictures of 562 * 762 pixels. In our experiment, we selected a total of four emotions, i.e. fear, happiness, sadness, and anger. We used a total of 36 different pictures per session (i.e. 12 images per condition, 6 males and 6 females), and each emotion was displayed by a different person. Those pictures considered unclear were discarded.

Music Material

Music used in the study was drawn from the dataset of a soundtrack for music and emotion created at the University of Jyväskylä, Finland. The dataset consists of a set of 360 audio clips of soundtracks that had been specifically composed to trigger five emotional states: anger, fear, relaxation, happiness, and sadness. Excerpts were 20 s in duration each; did not contain lyrics, dialogue, or sound effects (e.g. car sounds); and were not familiar to any of the participants. In the study, we used audio clips for anger, fear, happiness, and sadness in order to match the emotions portrayed by the selected visual stimuli.

Data Acquisition and Processing

EEG data were acquired using the Emotiv EPOC EEG system (Emotiv 2014). The system consists of 16 wet saline electrodes, 14 EEG channels, and a wireless amplifier. Electrodes were located at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4 according to the international 10–20 system (see Fig. 3.1). Reference electrodes were located at P3 and P4 (above the participants' ears). Data were digitized using the Emotiv EPOC built-in 16-bit ADC with 128 Hz sampling frequency per channel and sent to the computer via Bluetooth. The resulting EEG data were filtered using Butterworth 8–12 Hz and 12–28 Hz filters. The Emotiv Control Panel software was used to visually monitor electrode contact impedance to the scalp.

The Emotiv EPOC EEG device is a low-cost EEG device, which captures a lower-quality signal compared to other more expensive types of equipment.

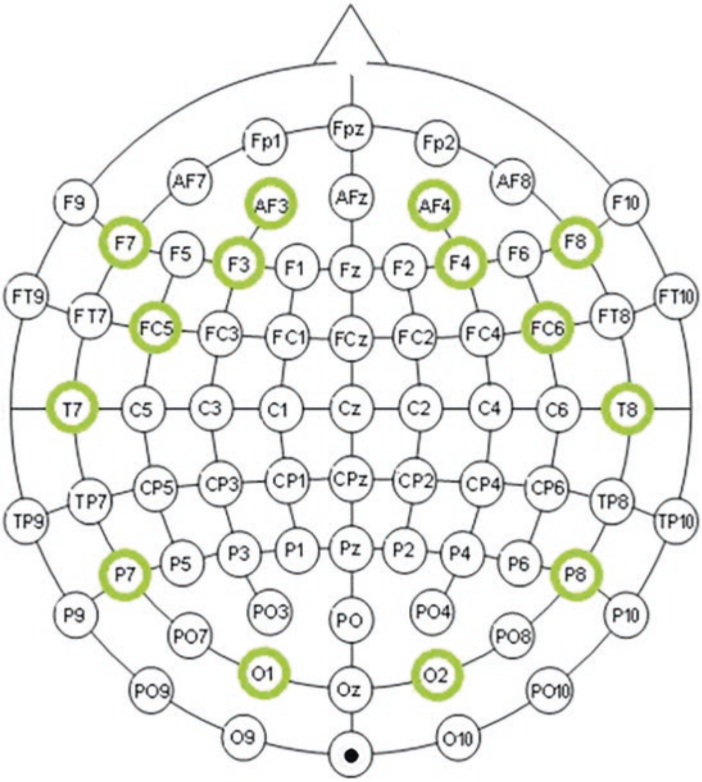

Fig. 3.1 International 10–20 system showing the electrode positions in the Emotiv EPOC

However, low-cost EEG devices can be reliable for measuring EEG signals for research purposes (Debener et al. 2012; Thie et al. 2012; Badcock et al. 2013). A review of the Emotiv EPOC EEG device, as well as of other low-cost systems, can be found in Badcock et al. (2013). For recording and processing the EEG data, as well as for synchronously presenting the images and audio clips, the OpenViBE platform (Renard et al. 2010) was used.

3.2.3 Methods

Experiment Design

We conducted a controlled study over the course of four consecutive weeks. Using the method of randomly permuted blocks, participants were randomly assigned into two groups: an experimental group EG (N = 14) and a control group CG (N = 11). Each participant was exposed to three sequential conditions in each session. Conditions for the EG participants were no-music (NM1), music (M), and no-music (NM3), while participants in the CG were exposed to three no-music conditions

(NM1, NM2, and NM3). In each condition, a total of 12 stimuli with emotional content (3 happy, 3 sad, 3 angry, and 3 fear) were presented in random order to the participants. The stimuli presented in conditions NM1, NM2, and NM3 were images drawn from the Karolinska Directed Emotional Faces database one at a time, while in condition M, in addition to the facial expression image, an emotion-matching music excerpt from the soundtrack database was concurrently presented. In each condition, 12 stimuli were presented in random order (6 males +6 females). No image nor music excerpt was presented twice to a participant during the study. The stimuli duration was 10 s with a 5 s transition (i.e. a black screen and no sound) among stimuli. During stimuli transitions, participants responded to the question, "How is this person feeling?" No instructions about their replies to the question were given to participants. Participants' verbal and EEG activity responses were recorded. The person collecting the responses stood behind the participants, so participants could not see or receive any facial, vocal, or bodily gesture cues from the person. Participants did not receive any type of feedback about the correctness of their replies during the whole study. No incentives were given to the children participating in the study, and all of them were willing to participate following the instructions.

Statistical Analysis

Verbal responses were analysed using the SPSS statistics software (IBM Corp., New York, NY, USA, 2010). We were interested in testing two hypotheses regarding verbal responses: (1) if there was an improvement in response accuracy within the same session between the first and the third conditions and (2) if there was an improvement in response accuracy in the last session compared to the first session for the first condition. For testing the first hypothesis, the assumption for normality was tested through the Shapiro–Wilk test for normality ($p \leq 0.05$), resulting in data that differed significantly from a normal distribution. A Wilcoxon matched-pairs signed-ranks test was performed to check whether there had been an improvement within the same session between the first and the third conditions. In order to test the second hypothesis, the normality of the data in the first condition for all sessions was tested with the Shapiro–Wilk test for normality ($p \leq 0.05$); data did not differ from a normally distributed data set. A test for a within-subjects, repeated measures study design was performed so as to verify whether there was a significant difference through the course of the sessions. A paired-samples ANOVA was run, thus allowing us to contrast the scores in the first condition along the intervention.

EEG Analysis

EEG data recorded from participants were normalized and transformed into a series of arousal and valence values in the Thayer's emotion plane (Thayer 1989), depicted in Fig. 3.2. EEG data were processed following Ramirez and Vamvakousis (2012). Ramirez and Vamvakousis (2012) showed that the computed arousal and valence values contain meaningful information about the user's emotional state. Artefact detection/elimination was performed by visual inspection of the signal. Arousal levels were computed as the ratio of EEG beta (12–28 Hz) and alpha (8–12 Hz) brainwaves (see Eq. 3.1) recorded at four locations on the prefrontal cortex: AF3, AF4,

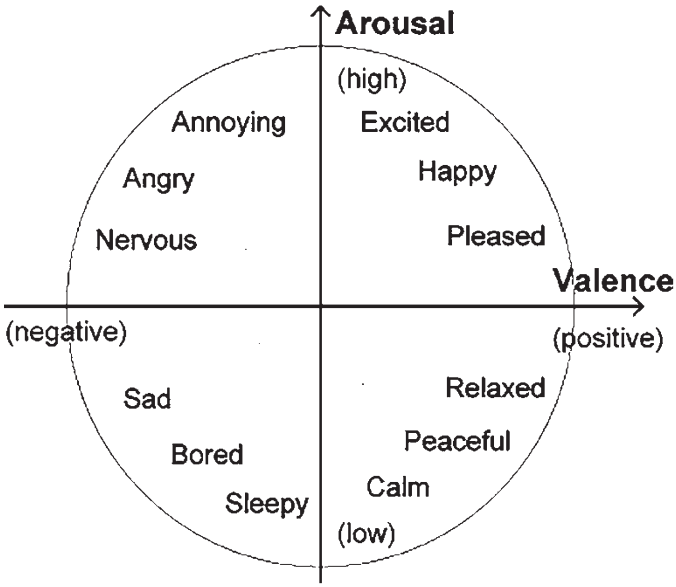

Fig. 3.2 Thayer's arousal–valence emotional plane

F3, and F4 (see Fig.3.1). Concretely, instantaneous arousal levels were computed as specified by Eq. (3.1):

$$\text{Arousal} = \left(\beta \text{F3} + \beta \text{F4} + \beta \text{AF3} + \beta \text{AF4}\right) / \left(\alpha \text{F3} + \alpha \text{F4} + \alpha \text{AF3} + \alpha \text{AF4}\right) \quad (3.1)$$

Motivated by previous EEG studies (Henriques and Davidson 1991; Davidson 1992, 1995, 1998), valence values were computed as the difference between alpha power α in the right and left frontal area (i.e. in channels F4 and F3). Positions F3 and F4 are the most commonly used positions for computing valence, as they are located in the prefrontal lobe, which plays a central role in emotion regulation. More precisely, valence levels were computed as specified by Eq. (3.2):

$$\text{Valence} = \alpha \text{F4} - \alpha \text{F3} \quad (3.2)$$

The above arousal level computation is motivated by the fact that beta waves are associated with alert and excited states of mind, whereas alpha waves are more dominant in a relaxed state. Thus, the beta/alpha ratio is a reasonable indicator of the arousal state of a person. Similarly, valence computation is motivated by psychophysiological research, which has shown the importance of the difference in activation between the cortical hemispheres. Left frontal inactivation is an indicator of a withdrawal response, which is often linked to negative emotion. On the other hand, right frontal inactivation may be associated with an approach response or positive emotion. Positions AF3, F3, AF4, and F4 are the most commonly used positions for computing arousal and valence, as they are located in the prefrontal lobe, which plays a central role in emotion regulation.

For each condition, EEG data were segmented according to the different emotional stimuli presented, i.e. EEG data were divided into data recorded during the presentation of happiness, sadness, anger, and fear emotion stimuli. For the non-music (NM) condition in session 1 and post-session 4, machine learning techniques were applied to train computational models to predict the class of stimuli (happy, sad, angry, and fear) from the arousal/valence descriptors extracted from the EEG activity. Concretely, the EEG signal was processed to extract instantaneous arousal and valence values, and these values were used to train an artificial neural network (a 2-node input layer, two 3-node hidden layers, and a 4-node output layer) with happy, sad, angry, and fear as target classes. The predictive model was evaluated using stratified tenfold cross-validation. In addition, for each class and all participants, arousal–valence centroids for the NM1 condition of session 1 and post-session 4 were computed.

3.2.4 Results

A matched-pairs signed-ranks test was performed to check whether there was an improvement in the verbal response accuracy within the same session between the first (NM1) and the third (NM3) conditions. For both the EG and the CG, the test indicated that there was no statistically significant difference between NM1 and NM3, failing to confirm that in the EG, the music stimuli condition (M) had an immediate residual effect on the NM3 condition within sessions.

A test for a within-subjects repeated measures study design was performed so as to verify whether there was a significant difference in the verbal response accuracy of the first and last sessions. With this purpose, we compared the verbal response accuracies in the NM1 condition of the first session with an NM1 a week after the last session. Table 3.1 shows the statistics of verbal responses of condition NM1 (first session) and condition NM1 a week after the last session for both the EG and the CG. The results show a statistically significant effect in the EG ($p = 0.011$), while no significance was found in the CG ($p = 0.695$). This result shows that the EG participants' scores in NM1 had significantly increased at the end of the study with respect to the beginning of the study. It is important to note that participants did not receive any type of feedback about the correctness of their replies during the whole study. The person collecting the responses was, at all times, standing behind the participants, so participants could not see or receive any facial, vocal, or bodily

Table 3.1 Statistics of verbal responses of condition NM1 (S1) and NM1 (post S4)

Group	Mean	SD	t-value	*p*-value
EG	1.667	0.422	3.953	0.011
CG	0.167	0.983	0.415	0.695

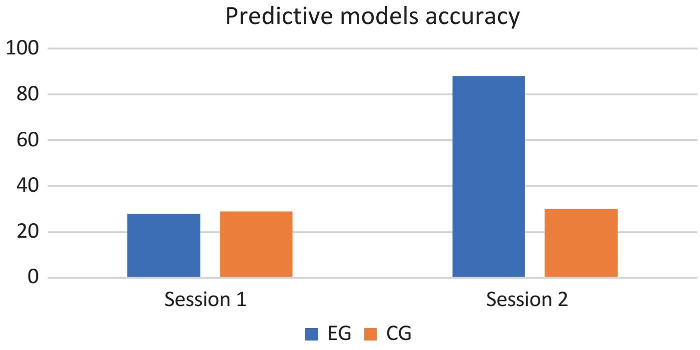

Fig. 3.3 Correctly classified instances percentages (CCI%) of classification models obtained by training with the arousal and valence values for NM1 session 1 and NM1 post-session 4

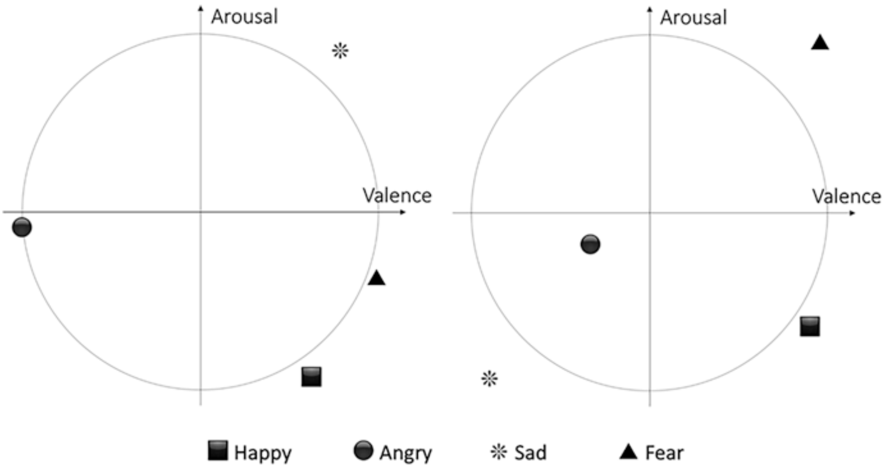

Fig. 3.4 Session 1 and post-session 4 normalized averaged (centroids) arousal and valence values in NM1 condition for the four emotional stimuli considered

gesture cues from the experimenter. This rules out the possibility that the resulting significant improvement in accuracy was simply due to habituation or practice. Thus, such improvement seemed to be due to the effect of music.

The accuracies of the computational predictive models obtained by training an artificial neural network with the arousal and valence values for condition NM1 in session 1 and condition NM1 a week after the last session for participants in the EG and CG are shown in Fig. 3.3. The difference between NM1 session 1 and NM1 a week after the last session in the EG was significant ($p = 0.002$), while no significant difference was found in the CG.

Average arousal and valence values were computed for each type of emotion stimuli in condition NM in session 1 and in session 4. Figure 3.4 shows normalized averages plotted in the arousal (*y*-axis) valence (*x*-axis) plane.

3.2.5 Discussion

There was no significant difference in verbal response accuracy between the two non-music conditions (NM1 and NM2) in the same session. This confirms that the music stimuli in the intermediate condition (M) had no immediate residual effect on NM2 in terms of verbal responses. This result is not surprising since expecting a significant effect of a sole music condition seems unreasonable. However, the effect of two consecutive sessions on a third one (S1–S3 and S2–S4) was found significant. As expected, the global effect of the study (S1–S4) was the most significant. Interestingly, the effect of the second session (S2) on the third one (S3) was also found to be significant. The reason for this may be that S1 had an accumulative effect on S2 and thus on S3.

The difference between the classification accuracy obtained by the trained models and the accuracy of the baseline classifier (25% in the case of the balanced four-class emotion classification task) indicates that arousal and valence indicators extracted from the EEG data contain sufficient information to distinguish the emotional states produced by the different stimuli and that the machine learning method applied is capable of learning the EEG patterns that distinguish these states. It is worth noting that the machine learning algorithm investigated, i.e. artificial neural networks (ANNs), produced significantly better results than random classification accuracies for every participant. This supports our idea about the feasibility of training classifiers for the cognitive states produced by the different emotional stimuli considered. It is also worth noticing that ANNs produce non-linear models, so we tested support vector machines (SVMs) with a linear kernel to see if the results were maintained. The results of the SVM model were not significantly better than the baseline classifier for most of the participants, suggesting that the data are non-linearly distributed in the arousal–valence plane.

The obtained models' classification accuracies may be interpreted as an indicator of how differentiable the participants' emotional responses (estimated by their computed arousal and valence responses) are during different stimuli presentations. That is, if it was the case that stimuli did not have any emotional effect whatsoever on the participants and thus did not produce any differentiable EEG responses, the accuracies of the models would be expected to be close to baseline (25%). The fact that the participants' emotional responses are consistently more easily classified post-session 4 compared with the first session may indicate that the repeated presentation of the stimuli presentation throughout the study has an effect on the neural encoding of the emotional stimuli. However, this does not imply that the resulting neural encoding does actually correspond with the emotion being presented. In order to investigate the neural encoding relation with the stimuli, the presented arousal and valence indicators were computed at the beginning and the end of the study.

Average arousal and valence values were computed for each type of emotional stimuli in session 1 and post-session 4 for condition NM. Figure 3.4 (left) shows the result for session 1: There is no correlation between the relative arousal and valence values and the emotion presented in the corresponding stimuli. In Fig. 3.4 (right), which shows the result for post-session 4, there is a partial correlation between the relative arousal and valence values and the emotion presented in the corresponding stimuli. Happy, sad, and angry stimuli seem to be encoded as expected according to the EEG activity, although the valence of fear stimuli appears to be wrongly encoded.

It has to be noted that ideally a neurotypical children group exposed to visual and auditory stimuli could have been included in the study. In this way, it would have been possible to both quantify the added value of music for improving facial emotion recognition in children with ASD and compare the results of the ASD study with the results of neurotypical children.

In summary, the use of music seemed to produce a significant improvement in the emotion identification accuracy of verbal responses within four sessions. Furthermore, participants' emotional responses computed from their EEG data after the last session showed a better correlation with the emotional stimuli being presented compared with their emotional responses in the first session. Results seem to indicate that music can be used to improve both emotion identification and emotion induction of facial expressions in children with high-functioning ASD.

3.3 Protocol for a Music-Based Intervention for Improving Emotion Recognition in Children with ASD (IER-ASD)

Introduction

This protocol outlines a structured approach to using a music-based intervention for improving emotion recognition in children with autism spectrum disorder (ASD). The protocol is grounded in the findings of the study described in Sect. 3.2 of this chapter. The intervention involves using music to enhance emotional processing in individuals with ASD, with a focus on improving their ability to recognize emotions encoded in stimuli with emotional content such as facial expressions, postures, videos, or daily-life situations.

Assessment

The first step in the protocol is to conduct a comprehensive assessment of the person's emotional and social skills. The assessment should include standardized measures of emotional processing, such as the Diagnostic Analysis of Nonverbal Accuracy 2 (e.g. DANVA2-CF for assessing children and DANVA2-AF for assessing adults) and the Reading the Mind in the Eyes Test (RMET for assessing adults), and measures of social skills, such as the Social Responsiveness Scale (SRS for assessing children). The assessment can also include a qualitative evaluation of the child's strengths and challenges, including their sensory processing and communication abilities. Finally, the assessment may include a recognition task of the stimuli used in the intervention. That is, the child may be presented with a series of stimuli, e.g. images of facial expressions if that is the stimuli to be worked with in the intervention, depicting the emotions of happiness, sadness, anger, and fear. They should be asked to identify the emotion expressed in each image.

Intervention
The intervention should be tailored to the child's individual needs and preferences. The intervention should consist of at least four weekly sessions, conducted by a trained music therapist. The intervention should be designed to enhance emotion recognition in children with ASD, using music to reinforce the identification of emotions encoded in the stimuli with emotional content, for instance, facial expressions. The intervention should include the following:

Music listening: The person should be exposed to music that evokes the same emotion as the emotional stimuli being shown. For example, if a sad stimulus is being shown, sad music should be played.

Music and stimuli recognition task: The person should be presented with a series of stimuli, e.g. images of facial expressions, depicting the emotions of happiness, sadness, anger, and fear. The same emotions should be evoked by playing music that is congruent with the facial expression. For example, if a sad facial expression is being shown, sad music should be played. The person should be asked to identify the emotion expressed in each image while the music is playing.

Outcome Measures
The progress of the person should be monitored at the end of the intervention using the same standardized measures of emotional and social skills, such as the RMET, DANVA-2, and SRS, used in the assessment prior to the intervention in order to evaluate the effect of the intervention. If possible, the progress of the person may be regularly monitored during the course of the intervention too. In addition, progress should be evaluated using observations of their emotional expression and social interaction in naturalistic settings. The child's feedback on their experience of the intervention should also be sought to guide any necessary modifications to the intervention.

Modifications
Modifications to the intervention may be necessary based on the individual's progress, preferences, and needs. Modifications may include changes to the type of music used, the intensity and duration of the sessions, and the level of social interaction involved in the intervention. Modifications should be made in collaboration with the child and the child's family and carefully evaluated for their effectiveness.

Ethical Considerations
Participants (and their parents or guardians in the case of children) will be informed about the intervention process before consenting to participate. A consent form

should be signed by the participants at the beginning of the intervention. Participants will be free to withdraw from the intervention at any time without any negative consequences.

Conclusion

The music-based intervention for improving emotion recognition in children with autism spectrum disorder is a structured approach to enhancing emotional processing in children with ASD. The protocol is grounded in the findings of the pilot study described earlier and provides a framework for conducting music interventions in a clinical setting. The protocol emphasizes the importance of individualized assessment, tailored interventions, regular monitoring of progress, and modifications based on individual needs.

3.4 Chapter Summary

This chapter explores the potential benefits of utilizing music to enhance the skills of children diagnosed with autistic spectrum disorder (ASD). Specifically, we present a study investigating the effectiveness of music as a tool for improving emotion recognition in high-functioning ASD children when presented with facial expressions. Results revealed that following the music-based intervention, children with ASD demonstrated a notable improvement in their ability to accurately identify emotions through verbal responses compared to their performance prior to the intervention. Further analysis of post-intervention EEG activity demonstrated an alignment of emotional responses with the presented stimuli, suggesting improved empathy as well as emotion identification. These findings support the development of a music-based intervention protocol (IER-ASD) for enhancing emotion recognition in children with ASD.

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Chapter 4
Music and *Stroke Rehabilitation*

Contents

4.1 Stroke

A stroke is a serious, life-threatening medical condition that occurs when the blood supply to a part of the brain is interrupted or severely reduced. This deprives brain tissues of essential nutrients and oxygen, and brain cells begin to die within minutes. There are two main types of strokes: ischemic and haemorrhagic. Ischemic strokes, which account for about 85% of all strokes, occur when the arteries to your brain become narrowed or blocked, causing a severely reduced blood flow. This can be due to blood clots, which can either form in the brain's blood vessels (thrombotic stroke) or elsewhere in the body and travel to the brain (embolic stroke). Haemorrhagic strokes occur when a blood vessel in your brain leaks or ruptures. This could be due to conditions such as hypertension, overuse of anticoagulants, or aneurysms.

Stroke is one of the most pre-eminent causes of mortality and morbidity in the world (Black et al. 2015). In 2017 alone, there were 1.12 million strokes in the European Union, 9.53 million stroke survivors, 0.46 million deaths, and 7.06

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million disability-adjusted life years lost because of stroke. The World Health Organization (WHO) has given special attention to the need to investigate and collect data on rehabilitation (Sauzet et al. 2015). Still, the rehabilitation of stroke patients remains a challenge, and there is a need for high-quality quantitative data. Although traditional physiotherapy and rehabilitation techniques have been shown to be effective in treating hemiparesis, such techniques present several limitations and are not always accepted by patients. Some of these techniques demand high tolerance, perseverance, and cooperation from the patients, which can lead to frustration (Pulman et al. 2013). Even well-established standard physiotherapies do not fully provide evidence of efficacy for motor behaviour improvement (Hakkennes and Keating 2005; Peurala et al. 2012; Stevenson et al. 2012). Therefore, new innovative, motivating, engaging, and goal-directed training protocols for stroke rehabilitation are necessary.

4.2 Music and Stroke Rehabilitation

Music and music-based interventions have been used in different clinical contexts producing positive effects in people with cognitive, emotional, and motor function impairments (Schlaug 2009; Schlaug et al. 2010). With the advent of brain imaging techniques such as electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI), it has been shown that music activity, both music listening and music making, activates a broad and complex network of brain areas related to auditory, cognitive, sensory-motor, and emotional processes (e.g. Ellis and Thayer 2010; Särkämö et al. 2008). In particular, it has been shown that music playing can effectively improve motor skill recovery in stroke patients (Altenmüller et al. 2009; Altenmüller and Schlaug 2013; Schneider et al. 2007; Stevenson et al. 2012; Thaut and Abiru 2010). For instance, Schneider et al. (2007) studied stroke patient rehabilitation by comparing music-based training (piano and drum playing), constraint-induced movement therapy (CIMT, a therapy that focuses on the affected limb while restraining the unaffected limb) (Morris et al. 2006) and conventional physiotherapy. For motor rehabilitation, they found that music-based training was more effective than CIMT and conventional physiotherapy in terms of both a set of established motor tests and a computer-based motor analysis. In addition, patients described music-based training as an enjoyable and motivating activity, which has been identified as an important aspect of successful recovery (Schneider et al. 2007). It has been found that music (both listening and playing) positively affects mood and motivation in stroke and affective disorders patients (Koelsch et al. 2010; Forsblom et al. 2009; Särkämö et al. 2008).

Music-based therapy using traditional music instruments for stroke patients is often limited and restricted due to a lack of fine motor skills. Stroke patients with motor skills severely affected are often incapable of effectively playing a traditional musical instrument. Incorporating technology could prove to be advantageous in establishing a connection between music therapists and their clients. Many experts in the field have recognized the potential of technology to not only revolutionize the analysis of therapy sessions but also enhance the therapeutic journey for clients. In light of this, we suggest utilizing musical technologies as a part of daily music therapy practice, where interactive systems technology can capture user movements and translate them into audiovisual and haptic feedback. This way, technology can be effectively integrated into the appropriate domain of music therapy. In this context, accessible digital musical interfaces (ADMIs) provide a possible alternative for allowing stroke patients to enjoy music playing and its associated benefits. There have been several accessible digital musical interfaces (ADMIs) proposed for people with different types of motor disabilities, for instance, the EyeHarp (Vamvakousis and Ramirez 2016). For a description of some of them, please refer to Chap. 2.

In the next section, we present a pilot study to investigate the effect of music therapy and adaptive digital music interfaces in the upper limb rehabilitation of stroke patients. We conducted a randomized, double-blind, controlled, longitudinal clinical study with chronic stroke patients. Patients in the control group (CG, N = 15) received 60 min of traditional physiotherapy, while for patients in the experimental group (EG, N = 15), 10 of these 60 min were replaced by music-based therapy using the MyoMusic adaptive digital interface. The MyoMusic is controlled by a motion capture (MoCap) sensor and eight electromyogram (EMG) sensors. All patients received 25 therapy sessions during 6 weeks. Patients were blindly evaluated at the beginning and at the end of the treatment by applying the Fugl-Meyer assessment for the upper extremities (FMA-UEs) as a primary outcome measure of motor recovery.

4.3 Research: Music and Motion Sensing for Stroke Rehabilitation

4.3.1 Participants

The research reported in this chapter is the result of a collaboration between the Rehabilitation Unit, Parc de Salut Mar, Hospital del Mar/Hospital de la Esperanza, Barcelona, and the Universitat Pompeu Fabra, Barcelona. Recruitment, interventions, and data collection are carried out at the Rehabilitation Unit. Data processing and analysis were carried out at the Universitat Pompeu Fabra. All stroke patients were assessed for eligibility according to predefined inclusion and exclusion criteria shown in Table 4.1.

Thirty adults (10 females and 20 males, mean = 67 years old, SD = 11) having suffered an (ischemic or haemorrhagic) stroke within the previous 3 months and with normal hearing participated in the study. Fifteen of them were randomly selected to participate in a music-based intervention consisting of playing an adaptive digital music interface with their upper limb affected by the stroke.

Table 4.1 Patients' inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Admitted to physiotherapy Suffered from ischemic or haemorrhagic stroke within the previous 3 months Patients affected by emiparesia or monoparesia Understanding of Spanish or Catalan language	More than one stroke Cognitive impairment Deafness Restlessness and agitation

4.3.2 Materials

Music Material

Music used in the music therapy sessions included familiar music pieces with different degrees of difficulty:

- *Twinkle Little star*. Low difficulty level. Contiguous notes, mostly lower pitches (on the left in the interface) with quarter note rhythm.
- *Frére Jacques*. Medium difficulty level. Notes of a wider pitch range, mostly of high pitch (on the right side in the interface), but with some lower pitch (on the left side in the interface), with eighth notes rhythm.
- *Ode to Joy (Ludwig van Beethoven).* Medium/moderate difficulty level. Mostly contiguous notes but often played at faster tempi.
- *Children's Songs #1 (Chick Corea).* High difficulty level. Notes alternating between low and high pitch (i.e. wide range arm mobility), high difficulty level due to the ability required to concentrate in slow tempi sections and agility and precision of movements in fast tempi sections.

The pieces were chosen to ensure that participants were already familiar with them (except maybe *Children's Songs*). Songs were played at different tempi and with different spatial–pitch mappings, to match the abilities of each participant.

Data Acquisition and Processing

The Myo device, a highly sensitive nine-axis Inertial Measurement Unit (IMU) device, was used to acquire information from the affected forearm motion during the music intervention. The Myo device is a bracelet composed of a set of sensors for motion estimation and a haptic feedback motor. The bracelet size is between 19 and 34 cm adjustable to the forearm circumference. It weighs 93 g. The hardware comprises eight medical-grade stainless steel Electromyogram (EMG) sensors reporting electrical muscle activity. The IMU contains a three-axis gyroscope giving degrees of change in radians per second (angular velocity), a three-axis accelerometer as an estimation of −8 g to 8 g (1 g = 9.81 m/s2), a three-axis magnetometer giving an output a Quaternion reference of the imaginary rotation of the Myo in the space. It has an ARM Cortex M4 Processor, and it may provide short, medium, and long haptic feedback vibration. Its communication with a computer is based on Bluetooth with an included adapter, giving a sampling rate of 200 Hz (Hop time of 5 ms).

Participants used MyoMusic, a motion capture system created by the Music and Machine Learning Lab at the Universitat Pompeu Fabra, which uses the Myo as an input device and implements a graphical interface that displays the position of the

Myo device (and therefore of the participant's arm in real time). The MyoMusic is used to trigger sounds depending on the Myo position. The interface displays notes arranged horizontally with a descending pitch order (higher notes on the right side). Once the exercise starts, a series of spheres fall into different positions, each one representing a musical note. Participants have to position their affected arm to "catch" the spheres in such a way that the position represented by their arm coincides with the falling spheres at the right time, which in turn triggers the corresponding sounds. When notes are "caught", they break into pieces, each of which represents a possible ornament of the performed melody. See Fig. 4.1 for a screenshot of the music interface.

The application allows you to change the speed, calibrate, and recalibrate the range of horizontal amplitude of the movement of the arm and select the piece, each with a different degree of complexity. At the end of each piece, an overall score is displayed (see Fig. 4.2) and the patient is encouraged to interact with small sonic objects as a reward. The score may be used for monitoring the difficulty of the task and the progress of the patient.

Recording: In order to record the gestures and synchronize the Myo device with video and audio data, a Max/MSP program was implemented, which sends Open Sound Control (OSC) events to the Myo application to generate a database of Comma Separated Values (CSV) files; it records the data at 60fps. These files are created with the format: timer in milliseconds, accelerometer (x, y, z), gyroscope (x, y, z), Quaternion (w,x,y,z), electromyogram (eight values), point_vector(x,y,z),

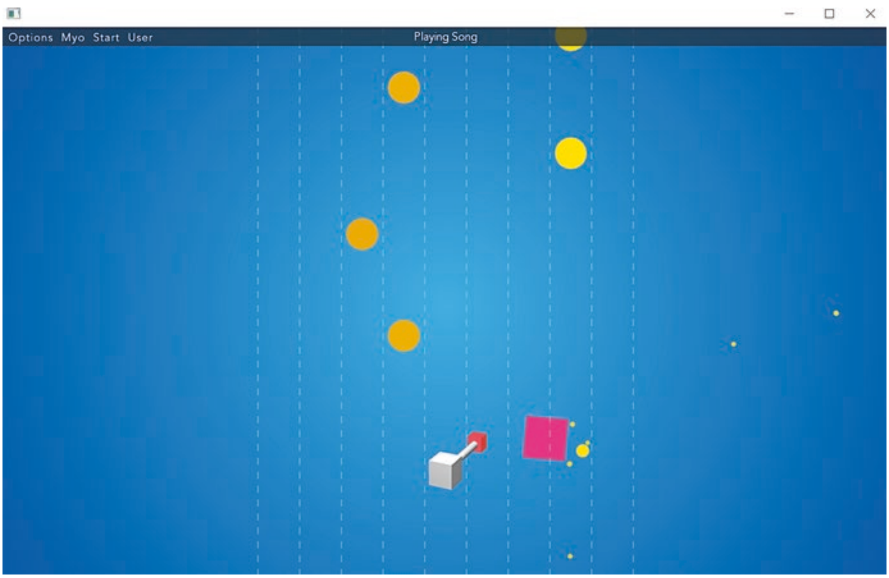

Fig. 4.1 The MyoMusic interface. Spheres represent notes; the square is the position of the patient's arm, and the task is to "catch" the spheres to trigger the corresponding notes. When notes are "caught," they break into pieces, each of which represents a possible ornament of the performed melody

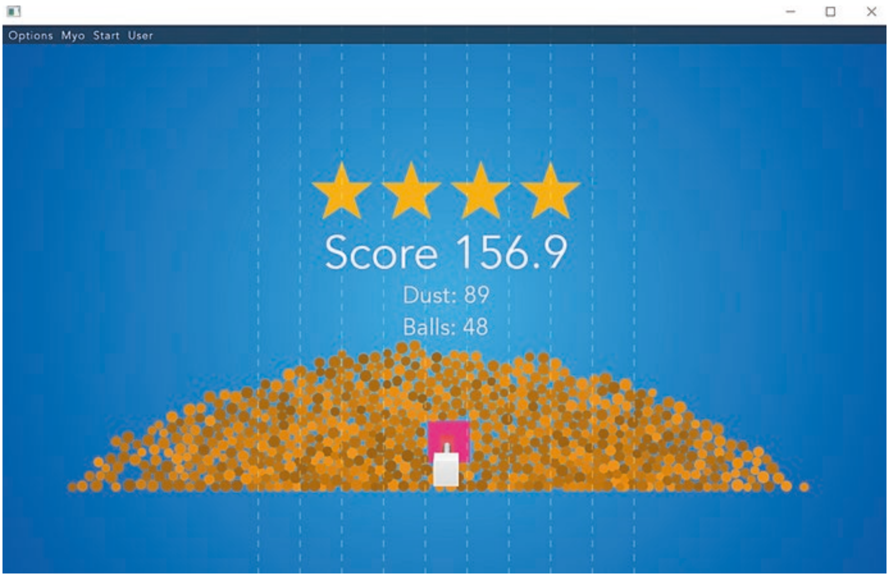

Fig. 4.2 At the end of each piece, an overall score is displayed to encourage the patient who interacts with small sonic objects as a reward

point_direction (x,y,z), point_velocity(x,y,z), and event (it is a marker during recordings). Those CSV files are recorded in the same time window range reference of the audio data, also created with Max.

Assessment tools. The Fugl-Meyer assessment (Fugl-Meyer et al. 1975; Gladstone et al. 2002) is a stroke-specific, performance-based impairment index. It is designed to assess motor functioning, balance, sensation, and joint functioning in patients with post-stroke hemiplegia. It is applied clinically and in research to determine disease severity, describe motor recovery, and plan and assess treatment. It is divided into four sections, shoulder/elbow/forearm, wrist, hand, and coordination/speed, in which different items are evaluated. It uses a quantitative scale from 0 to 2 points per item, with a total maximum total value of 66 points. The Chedoke Arm and Hand Activity Inventory is a rating scale consisting of 13 functional tasks. It is a measure of upper extremity functionality that uses a quantitative scale of 1 to 7 points per task, with a total sum of 91 points as the maximum score. Its purpose is to assess the functional capacity of the affected arm and hand, in conjunction with the unaffected side, in tasks that have previously been identified as important after a cerebrovascular accident. Its purpose is to promote bilateral function.

4.3.3 Methods

Patients eligible for inclusion in the study were contacted at the Rehabilitation Unit, Parc de Salut Mar, and informed about the procedures and objectives of the study. Patients received no information about which of the two interventions was the actual

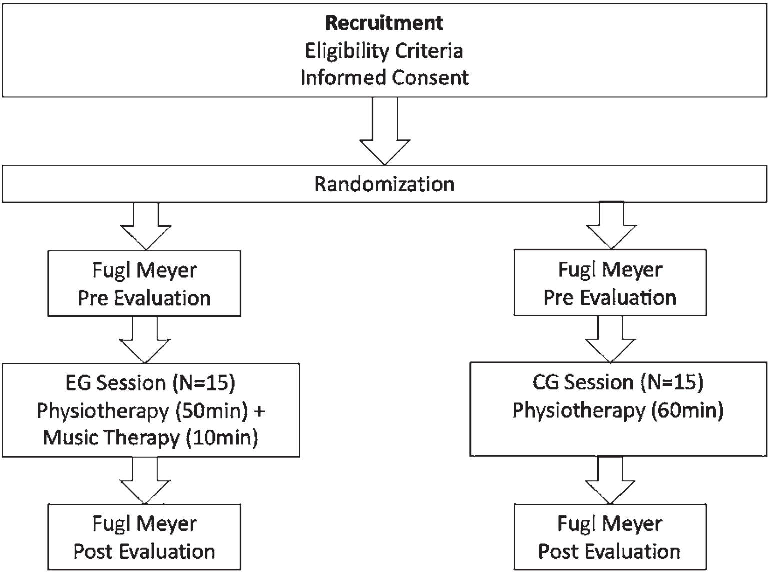

Fig. 4.3 Flow diagram of the study design

experimental condition. If patients agreed to participate, they were asked to sign the informed consent form. Participants were treated individually. Participants in the experimental group (EG) received physiotherapy sessions for 50 min and a music intervention with MyoMusic for 10 min, four times a week. The sessions were conducted by two professional music therapists with experience in rehabilitation care. Each music therapy session consisted of playing some of the music pieces (see above) with MyoMusic. Motion data was recorded during the music therapy session. Participants in the control group (CG) received 60 min of physiotherapy. All participants were receiving similar levels of medication at the moment of the study. Figure 4.3 shows a flow diagram of the study design.

In addition to motion data gathering, participants were blindly assessed using the Fugl-Meyer evaluation method, both before the first session (pre) and after the last session (post). Data were analysed by applying a t-test of pre- and post-values.

4.3.4 Results

Fugl-Meyer and Chedoke Assessment The experimental and control groups improved their rehabilitation of the upper limb. However, the improvement was more significant for the experimental group ($p = 0.0016$) than for the control group ($p = 0.0122$) as measured by the Fugl-Meyer assessment. Similarly, the improvement was more significant for the experimental group ($p = 0.0002$) than for the

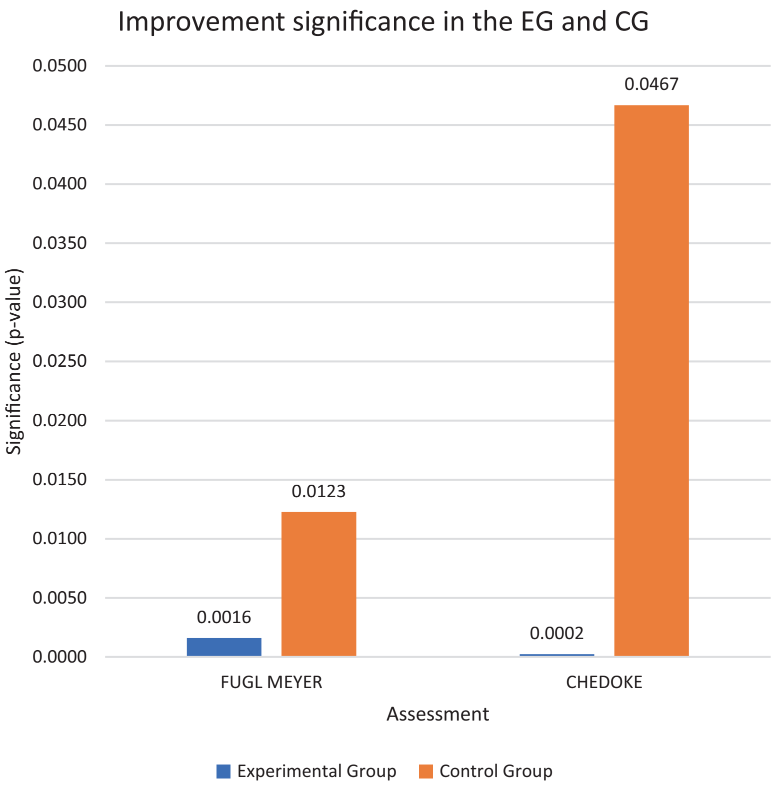

Fig. 4.4 Statistical significance of pre-post evaluation by the Fugl-Meyer and Chedoke assessments for the experimental group (blue) and control group (orange)

control group (p = 0.0466) as measured by the Chedoke assessment. Figure 4.4 shows the statistical significance of both groups for the Fugl-Meyer and Chedoke assessments.

4.3.5 Discussion

The Fugl-Meyer assessment results reveal that both the experimental and control groups experienced improvement post-rehabilitation. However, the experimental group exhibited a notably higher level of significance in improvement (p = 0.001) compared to the control group (p = 0.01). Although both traditional physiotherapy and the combination of physiotherapy with music therapy were anticipated to enhance upper limb rehabilitation, it was striking to see the experimental group achieve greater improvement by incorporating just 10 min of MyoMusic intervention per session.

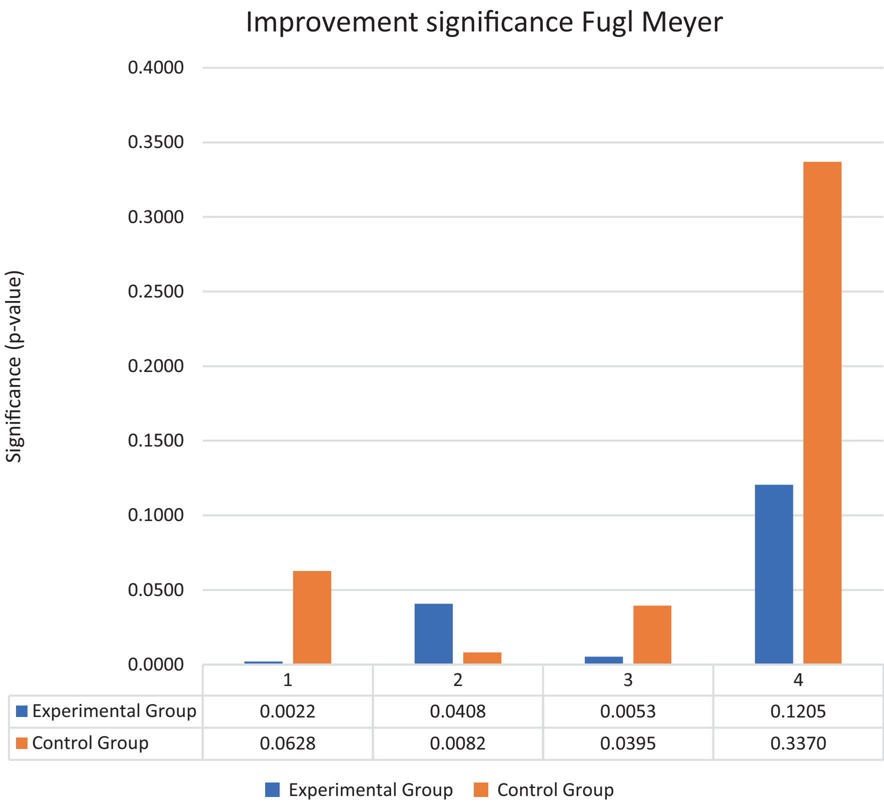

Fig. 4.5 Statistical significance of pre-post evaluation by the Fugl-Meyer assessment for the experimental group (blue) and control group (orange), for the following items: (1) shoulder/elbow/forearm, (2) wrist, (3) hand, and (4) coordination/speed

Delving deeper into the Fugl-Meyer assessment sections (refer to Fig. 4.5), the experimental group displayed a significant improvement in the shoulder, elbow, and forearm regions ($p = 0.002$). In contrast, the control group's progress was not statistically significant ($p = 0.062$). This observation aligns with the specific emphasis of the MyoMusic intervention on the shoulder, elbow, and forearm regions. As for wrist and hand rehabilitation, both groups registered significant progress. Specifically, the wrist exhibited significance levels of 0.04 and 0.008, and the hand at 0.005 and 0.039, for the experimental and control groups, respectively. In the domain of coordination and speed, neither group achieved significant progress. However, the experimental group exhibited a more pronounced improvement ($p = 0.12$) compared to the control group ($p = 0.33$).

Turning our attention to the Chedoke assessment (illustrated in Fig. 4.4), both groups made significant strides. Yet, while the control group's p value was borderline significant at $p = 0.046$, the experimental group showed a compelling level of significance at $p = 0.0002$.

The distinction between the experimental and control groups was the treatment regimen: The experimental group underwent 50 min of traditional physiotherapy combined with 10 min of MyoMusic intervention per session. In contrast, the control group solely received 60 min of traditional physiotherapy. Remarkably, the mere addition of 10 min with MyoMusic in each session resulted in noticeable improvements in the rehabilitation process for the experimental group. One direction of further research is to investigate the results of MyoMusic interventions with different lengths in order to assess the relative benefits of traditional physiotherapy and MyoMusic intervention.

The results reported in this chapter are based on a 25-session intervention with a post-evaluation right after the last session. Further research is needed to assess the long-term benefits of the intervention by evaluating both groups after a period of time as well as to assess the benefits of longer interventions. This will allow us to optimize the music-based intervention in terms of its duration per session and the number of sessions.

One of the advantages of using a digital music interface in stroke rehabilitation is that as all the motion data are processed by the computer, it is easy to monitor and track the patients' progress in a very precise manner. With MyoMusic, the data about limb position, orientation, velocity, reach, and muscle activity can be recorded and later analysed. Figure 4.6 shows the patients' average progress over the course of 25 sessions in terms of performed tempo (in beats per minute), the score computed by MyoMusic according to the number of correctly performed notes by the patients, and the arm reach, expressed as a percentage of the initial reach of each patient. As can be seen, there is a clear improvement in all three aspects. Although they played the pieces at a faster tempo every time, they kept improving their accuracy (i.e. MyoMusic score), and they had a wider arm movement.

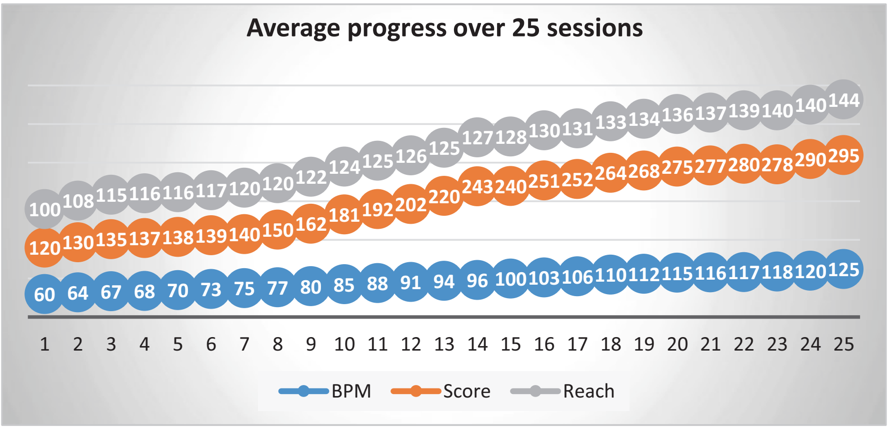

Fig. 4.6 Patients' average progress over the course of 25 sessions: performed tempo (in beats per minute) in blue, note accuracy MyoMusic score in orange, and arm reach (in %) relative to the initial reach in grey

4.4 Protocol: Music-Based Intervention for Stroke Rehabilitation

Objective: The overall objective of the intervention protocol is to improve motor recovery in chronic stroke patients through the use of music-based motor therapy. Specifically, the protocol aims to:

1. Enhance the effectiveness of a music-based motor therapy intervention compared to only traditional physiotherapy in improving motor recovery in chronic stroke patients.
2. Personalize the music-based motor therapy sessions to improve motor individual recovery in chronic stroke patients.
3. Maximize the extent to which the benefits of music-based motor therapy intervention generalize to other aspects of motor function, beyond the specific upper extremity movements targeted by the intervention.
4. Explore the potential mechanisms underlying the beneficial effects of music-based motor therapy on motor recovery in chronic stroke patients.
5. Assess the feasibility and acceptability of the music-based motor therapy intervention among chronic stroke patients and their caregivers.

By achieving these objectives, the intervention protocol aims to provide evidence-based guidelines for the use of music in stroke rehabilitation and to improve the quality of life of chronic stroke patients.

Population: Chronic stroke patients who have suffered from ischemic or haemorrhagic stroke within the previous 3 months, with normal hearing, affected by emiparesia or monoparesia, with no cognitive impairment.

Duration: 25 therapy sessions over the course of 6–10 weeks.

Outcome measure: Fugl-Meyer assessment for the upper extremities (FMA-UEs) as a primary outcome measure of motor recovery.

Protocol:

1. Patient evaluation: All patients will undergo an initial evaluation using the Fugl-Meyer assessment for the upper extremities (FMA-UEs) to determine baseline motor function.
2. The music preferences of each patient are identified in an interview. These preferences are then used to select music pieces that are integrated into the music therapy sessions, ensuring a personalized and engaging experience for each patient.
3. Treatment: Patients will receive 30 min of music-based motor therapy using either traditional music instruments or a motion-sensing-based adaptive music interface. Sessions should be individual and conducted by a professional and qualified music therapist. During the session, clients would perform familiar and simple melodies with clear rhythmical patterns using the affected limb, while the music therapist accompanies them with a traditional musical instrument. Arm movement span and melody tempo would be

adjusted at the beginning of each session according to the state and progress of each patient. If a motion-sensing-based adaptive music interface is used, motion data will be recorded in digital format (typically the same music interface will record the motion data).

4. Motor assessment: At the end of the treatment period, all patients will be evaluated using the Fugl-Meyer assessment for the upper extremities (FMA-UEs) to determine motor recovery. If motor data were acquired during the intervention, the data will be organized temporally and analyzed to assess progress within sessions.
5. Statistical analysis: The motor gains of both groups, as assessed by the Fugl-Meyer evaluation, will be analyzed to determine the effectiveness of the music-based motor therapy. The results will be compared and significance will be computed to determine the level of improvement. If data from a control group is available, the differences between the music therapy and control groups should be assessed.
6. Data interpretation: Results will be interpreted to determine the effectiveness of music-based motor therapy for improving motor recovery in chronic stroke patients.

Conclusion: The results of the intervention will be used to establish the effectiveness of music-based motor therapy in stroke rehabilitation.

4.5 Chapter Summary

This chapter discusses the potential benefits of integrating music and technology into stroke rehabilitation. Specifically, we present the findings of a randomized, double-blind, controlled, longitudinal clinical study that involved 30 chronic stroke patients. The control group (N = 15) received 60 min of traditional physiotherapy, while the experimental group (N = 15) received a music-based motor therapy using a motion-sensing-based adaptive music interface for 10 min in addition to the 60 min of traditional physiotherapy. Both groups underwent 25 therapy sessions over a period of 6 weeks. To measure motor recovery as the primary outcome, patients were blindly evaluated at the beginning and end of treatment using the Fugl-Meyer assessment for the upper extremities (FMA-UEs). At 25 sessions post-treatment, both groups demonstrated significant motor gains in wrist and hand movement. However, only the experimental group showed significant improvement ($p = 0.002$) in shoulder, elbow, and forearm movement as assessed by the Fugl-Meyer assessment. It is noteworthy that our music-based intervention specifically targeted these areas. These findings suggest that combining music and technology can be beneficial for improving motor recovery in chronic stroke patients. Based on these results, we proposed a music-based 25-session intervention protocol for stroke rehabilitation.

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Chapter 5
Musical Neurofeedback for *Emotional Disorders*

Contents

5.1 Depressive Disorder

Depressive disorder is a widespread psychiatric condition characterized by an increased risk of suicide, and the highest count of years lived with disability in the United States, according to the US Burden of Disease Collaborators' 2013 study. It is estimated that nearly 20% of Americans will endure a major depressive episode at some point in their lives (Hirschfeld 2012). Furthermore, up to 80% of these individuals will experience multiple depressive episodes (Bulloch et al. 2014). Given its high prevalence, recurring nature, and substantial personal and societal costs, it is unsurprising that the World Health Organization anticipates that depression will be the single most burdensome disease globally in this century (Moussavi et al. 2007).

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Advancements in brain imaging have enabled researchers to study depression by exploring the neural mechanisms that might underpin this condition (Foland-Ross et al. 2013). Specifically, neuroimaging studies have revealed structural and functional neural features important for the development of depression (Hamilton et al. 2013). These studies have also shown that anomalies in neural networks involving multiple brain regions, connected both structurally and functionally, are at the root of the cognitive disturbances documented in depression (Sacher et al. 2012). We strongly believe that neuroimaging is a promising tool for not only understanding the pathogenesis of depression but also for treating and alleviating depression in a safe, non-invasive manner. Indeed, neuroimaging can act as a bridge between the clinical understanding and diagnosis of depression and its treatment. In this chapter, we describe an approach to treat depression in elderly people using neuroimaging and music in a (neuro)feedback system.

5.2 Elderly People, Music, Emotions and Neurofeedback

There is ample research reporting on the importance and benefits of music for older adults (Ruud 1997; Cohen et al. 2002; McCaffrey 2008). Some studies suggest that music contributes to positive ageing by promoting self-esteem, feelings of competence, and independence while diminishing feelings of isolation (Hays and Minichiello 2005). Listening to music appears to be rated as a very pleasant experience by older adults since it promotes relaxation, decreases anxiety, and distracts people from unpleasant experiences (Cutshall et al. 2007; Ziv et al. 2007; Fukui and Toyoshima 2008). It can also evoke very strong feelings, both positive and negative, which very often result in physiological changes (Lundqvist et al. 2009). These positive effects also seem to be experienced by people with dementia (Särkämö et al. 2012, 2014; Hsu et al. 2015). All these findings have led many researchers to be interested in the topic of the contribution of music to the quality of life and to life satisfaction of older people (Vanderak et al. 1983). Music activities (both passive and active) can affect older adults' perceptions of their quality of life, valuing highly the non-musical dimensions of being involved in music activities such as physical, psychological, and social aspects (Coffman 2002; Cohen-Mansfield et al. 2011). Music experiences, led by music therapists or by other caregivers, besides being a source of entertainment, seem to provide older people with the mentioned benefits (Hays and Minichiello 2005; Solé et al. 2010). Music has been shown to be beneficial in patients with different medical conditions. Särkämö et al. (2010) demonstrated that stroke patients merely listening to music and speech after neural damage can induce long-term plastic changes in early sensory processing, which, in turn, may facilitate the recovery of higher cognitive functions. The Cochrane review by Maratos et al. (2008) highlighted the potential benefits of music therapy for improving mood in those with depression. Erkkilä et al. (2011) showed that music therapy combined with standard care is effective for depression among working-age people with depression.

Neurofeedback is a technique which uses real-time feedback of brain activity, often electroencephalography (EEG), in an attempt to teach self-regulation of brain function. Typically, EEG sensors are placed on the scalp to measure electrical activity produced by the neurons in the cortex, with measurements displayed using video displays or sound. Neurofeedback has been found to be effective in producing significant improvements in medical conditions such as depression (Kumano et al. 1996; Rosenfeld 2000; Hammond 2004), anxiety (Vanathy et al. 1998; Kerson et al. 2009), migraine (Walker 2011), epilepsy (Swingle 1998), attention-deficit/hyperactivity disorder (Moriyama et al. 2012), alcoholism/substance abuse (Peniston and Kulkosky 1990), and chronic pain (Jensen et al. 2007), among many others (Kropotov 2009). For instance, Sterman (2000) reports that 82% of the most severe, uncontrolled epileptics demonstrated a significant reduction in seizure frequency, with an average of 70% reduction in seizures. The benefits of neurofeedback in this context were shown to lead to significant normalization of brain activity even when patients were asleep. The effectiveness of neurofeedback was validated compared to medication and placebo (Kotchoubey et al. 2001). Similarly, Monastra et al.'s (2002) research found neurofeedback to be significantly more effective than Ritalin in changing Attention-deficit/hyperactivity disorder (ADD/ADHD), without having to remain on drugs. Other studies (Fuchs et al. 2003) have found comparable improvements with 20 h of neurofeedback training (40–30-min sessions) to those produced by Ritalin, even after only twenty 30-min sessions of neurofeedback (Rossiter and La Vaque 1995). In the context of depression treatment, there are several clinical protocols used to apply neurofeedback such as shifting the alpha predominance in the left hemisphere to the right by decreasing left-hemispheric alpha activity or increasing right hemispheric alpha activity, shifting an asymmetry index towards the right in order to rebalance activation levels in favour of the left hemisphere and the reduction of theta activity (4–8 Hz) in relation to beta (15–28 Hz) in the left prefrontal cortex (i.e. decrease in the theta/beta ratio on the left prefrontal cortex) (Gruzelier and Egner 2005; Michael et al. 2005; Ali et al. 2015). Dias and van Deusen (2011) applied a neurofeedback protocol that is simultaneously capable of providing the training demands of alpha asymmetry and increased beta/theta relationship in the left prefrontal cortex.

A still relatively new field of research in affective computing attempts to detect emotion states in users using electroencephalogram (EEG) data (Chanel et al. 2006). Alpha and beta wave activity may be used in different ways for detecting emotional (arousal and valence) states of mind in humans. For instance, Choppin (2000) proposes to use EEG signals for classifying six emotions using neural networks. Choppin's approach is based on emotional valence and arousal by characterizing valence, arousal, and dominance from EEG signals. He characterizes positive emotions by a high frontal coherence in alpha and high right parietal beta power. Higher arousal (excitation) is characterized by a higher beta power and coherence in the parietal lobe, plus lower alpha activity, while dominance (strength) of emotion is characterized as an increase in the beta/alpha activity ratio in the frontal lobe, plus an increase in beta activity at the parietal lobe. Ramirez and Vamvakousis (2012) characterize emotional states by computing arousal levels as the prefrontal cortex beta-to-alpha ratio and valence levels as the alpha asymmetry between lobes. They show that by applying machine learning techniques to the computed arousal and valence values, it is possible to classify the user emotion into high/low arousal and positive/negative valence emotional states, with average accuracies of 77.82% and 80.11%, respectively. These results show that the computed arousal and valence values indeed contain meaningful user emotional information.

In this chapter, we describe the potential benefits of combining music, neurofeedback, and emotion detection for improving elderly people's mental health. Specifically, we describe the emotional reinforcement capacity of automatic music neurofeedback systems and its effects on improving depression in elderly people. With this aim, we explain a new neurofeedback approach, which allows patients to manipulate expressive parameters in music performances using their emotional state. The patients' instantaneous emotional state is characterized by emotional parameters (i.e. a coordinate in the arousal–valence plane) decoded from their EEG activity. The resulting parameters are then used to change expressive aspects of music such as tempo, dynamics, and articulation. We describe the results of a pilot clinical study applying music neurofeedback to a group of elderly people with depression.

5.3 Research: Musical Neurofeedback for Depression Treatment in Elderly People

5.3.1 Brain Activity Acquisition

Brain activity data may be acquired by any EEG device with two or more channels. Similarly to the study reported in Chap. 3, in this study, we used the Emotiv EPOC EEG system (Emotiv 2014; Badcock et al. 2013) for acquiring the EEG data. Please refer to Chap. 3 (Sect. 3.2.2) for a description of the Emotiv EPOC EEG system.

5.3.2 Emotion State Estimation from EEG Data

The EEG data processing for valence and arousal computation is adapted from Ramirez and Vamvakousis (2012), where the authors show that the computed arousal and valence values contain meaningful users' emotional information. As in Chap. 3, emotion state estimation is performed as follows:

- *Arousal*. Based on the EEG signal of a person, the arousal level is determined by computing the ratio of the beta (12–28 Hz) and alpha (8–12 Hz) brainwaves. EEG signal is measured in four locations in the prefrontal cortex: AF3, AF4, F3, and F4. Beta waves β are associated with an alert or excited state of mind, whereas alpha waves α are more dominant in a relaxed state. Alpha activity has also been associated with brain inactivation. Thus, the beta/alpha ratio is a reasonable indicator of the arousal state of a person.

- *Valence***.** In order to determine the valence level, the activation levels of the two cortical hemispheres are compared. A large number of EEG studies (Henriques and Davidson 1991; Davidson 1992, 1995, 1998) have demonstrated that the left frontal area is associated with more positive affect and memories, and the right hemisphere is more involved in negative emotion. F3 and F4 are the most used positions for looking at this alpha/beta activity related to valence, as they are located in the prefrontal lobe, which plays a crucial role in emotion regulation and conscious experience. Thus, valence values are computed by comparing the alpha power α in channels F3 and F4.

5.3.3 Musical Neurofeedback

Once arousal and valence values are computed, they are fed into an expressive music performance system which calculates appropriate expressive transformations on timing, loudness, and articulation. The expressive performance system is based on a music performance model, which was obtained by training four models using machine learning techniques (Mitchell 1997) applied to recordings of musical pieces in four emotions: happy, relaxed, sad, and angry (each corresponding to a quadrant in the arousal–valence plane). The coefficients of the four models were interpolated in order to obtain intermediate models (in addition to the four trained models) and corresponding performance predictions. Details about the expressive music performance system and our approach to expressive performance modelling can be found in the study by Ramirez et al. 2010, 2012; Giraldo and Ramirez 2013.

5.3.4 Musical Neurofeedback and Depression: A Pilot Study

Based on the capture, analysis, and processing of data described in the previous section, we conducted a pilot clinical study applying musical neurofeedback to alleviate depression in elderly people. Ten adults (9 females and 1 male, mean = 84, SD = 5.8) with normal hearing participated in the neurofeedback study consisting of ten sessions (two sessions per week) of 15 min each. Participants granted their written consent, and procedures were positively evaluated by the Clinical Research Ethical Committee of the Parc de Salut Mar (CEIC-Parc de Salut Mar), Barcelona, Spain. Participants were either residents or day users in an elderly home in Barcelona and were selected according to their cognitive capacities, sensitivity to music, and depression condition: All of them declared to regularly listen to music and presented with a primary complaint of depression, which was confirmed by the psychologist of the centre.

Prior to the first session, the participants in the study were interviewed in order to determine the music they liked and to identify particular pieces to be included in their feedback sessions. Following the interviews, for each participant, a set of 5–6 music pieces was collected from commercial audio CDs. During each session, a subset of the selected pieces was played to the participant.

Participants were treated individually. At the beginning of each feedback session, participants were informed about the experiment procedure, were asked to sit in a comfortable chair facing two loudspeakers, close their eyes, and avoid moving during the experiment. Participants listened to preselected music pieces according to their music preferences for 15 min. Within these 15 min, music pieces were separated by a pause of 1 s. Participants were encouraged to increase the loudness and tempo of the pieces so the pieces sounded "happier". As the system was tuned so that increased arousal corresponded to increased loudness, and increased valence corresponded to increased tempo, participants were encouraged to increase their arousal and valence, in other words, to direct their emotional state to the high-arousal/positive-valence quadrant in the arousal–valence plane (see Fig. 5.1). At the end of each session, participants were asked if they perceived they were able to modify the music tempo and volume. Pre- and post-evaluation of participants were performed using the Beck Depression Inventory (BDI) depression test.

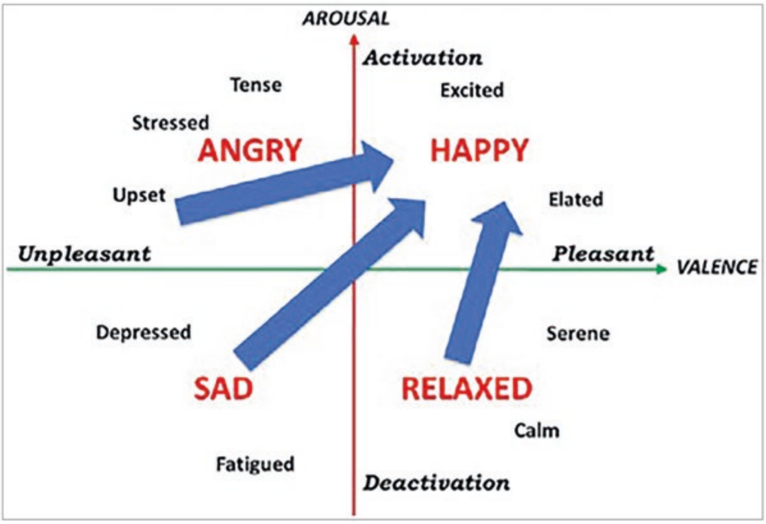

Fig. 5.1 Arousal–valence plane. By encouraging participants to increase the loudness and tempo of musical pieces, they were encouraged to increase their arousal and valence, and thus direct their emotional state to the top-right quadrant in the arousal–valence plane

5.3.5 Results

Seven participants completed training, requiring a total of ten 15-min sessions (2.5 h) of neurofeedback, with no other psychotherapy provided. There were four people who abandoned the study towards the end of it due to health problems. Pre- and post-evaluation of six participants were performed using the BDI depression test (one participant was not able to respond to the BDI depression test at the end of the treatment due to serious health reasons). The BDI evaluation performed using the BDI depression test showed an average improvement of 17.2% (1.3) in BDI scores at the end of the study. Pre–post changes on the BDI test are shown in Fig. 5.2.

We computed the average valence and arousal values at the beginning of the first session and the beginning of the last session of the study. The obtained average valence values were 0.74 (0.22) and 0.83 (0.26) for the beginning of the first session and the beginning of the last session, respectively, while the obtained average arousal values were 0.97 (0.14) and 0.98 (0.21) for the beginning of the first session and the beginning of the last session, respectively.

5.3.6 Discussion

Five out of six participants who responded to the BDI test made improvements in their BDI, and one patient improved from depressed to slight perturbation in the BDI scale. One participant, who initially scored as not depressed in the BDI pre-test (score = 1), did not show any improvement in her BDI post-score (score = 4), which was also in the non-depressed range. Either the participant was not depressed at the

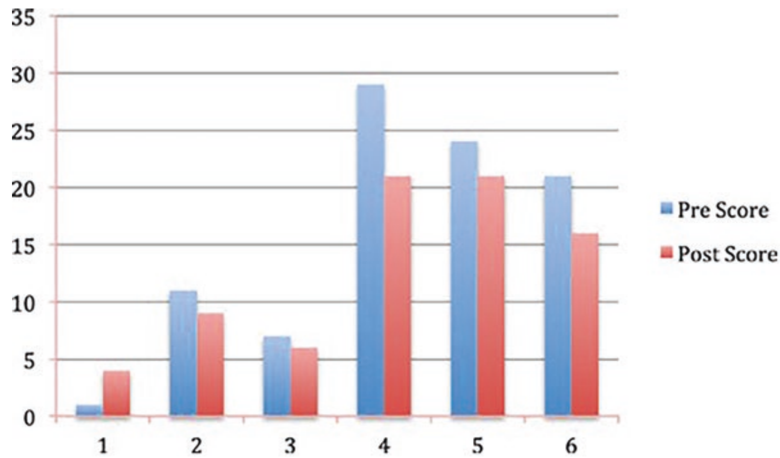

Fig. 5.2 Pre- and post-BDI depression test results for six participants

beginning of the study or her responses to the BDI tests were not reliable. Excluding her from the BDI test analysis, the mean decrease in BDI scores was 20.6% (0.06). These differences were found significant ($p = 0.018$).

EEG data obtained during the course of the study showed that the overall valence level increased at the end of the treatment compared to the starting level. The difference between valence values at the beginning and end of the study is statistically significant ($p = 0.00008$). This result should be interpreted as a decrease of relative alpha activity in the left frontal lobe, which may be interpreted as an improvement of the depression condition (Henriques and Davidson 1991; Gotlib et al. 1999). Arousal values at the beginning and at the end of the study showed no significant difference ($p = 0.33$). However, in this study, the most important indicator was valence since it reflects changes in negative/positive emotional states, which are directly related to depression conditions.

The correlation between valence values and time within sessions was found significant ($p < 0.00018$) but that was not the case for the correlation between arousal values and time. Again, the fact that the arousal–time correlation was not significant is not a negative result since valence is the most relevant indicator of depression.

Taking into account the obtained within- and cross-session improvements in valence levels and the limited duration of each session (i.e. 15 min) and the complete treatment (i.e. 10 sessions), it may be reasonable to think that further improvements in valence could have been reached if sessions and/or treatment had been longer.

In the current study, in addition to the post-study BDI test, no follow-up for the participants was conducted in order to examine the long-term effect of the intervention. In fact, very few studies in the literature have examined the long-term effect of neurofeedback. However, the few studies that did it found promising results (Gani et al. 2008; Gevensleben et al. 2010). Both Gani et al. (2008) and Gevensleben et al. (2010) showed that after the end of their studies, improvements were maintained and some additional benefits could be noted, suggesting that patients were still improving even after the end of treatment.

5.4 Protocol: Musical Neurofeedback for Depression Treatment

Objectives

The objective of this protocol is to alleviate depression in elderly people by using a musical neurofeedback approach. This protocol aims to describe the methodology of the intervention, including the materials needed, the selection criteria of participants, the neurofeedback system, and the evaluation criteria.

Participants

Inclusion criteria: People aged 60 years and above with a diagnosis of depression, normal hearing, and no history of neurological or psychiatric disorders.

Exclusion criteria: Participants with a history of neurological or psychiatric disorders, hearing impairment, and inability to understand or follow the instructions.

Materials

The equipment required to follow the neurofeedback protocol includes:

An EEG device: This device is used to acquire EEG data from the participants. It must consist of at least two channels placed on the prefrontal positions on both hemispheres, such as F3 and F4, or AF3 and AF4.

Computer: A computer is used to process the EEG data and control the neurofeedback system. The neurofeedback system should be able to provide real-time feedback of at least the alpha power. Ideally, it should provide real-time feedback on arousal and valence levels computed from the EEG data.

Loudspeakers: Two loudspeakers are used to play the music pieces selected for the experiment.

Comfortable chair: Participants are required to sit in a comfortable chair throughout the experiment.

BDI depression test: The BDI depression test is used to evaluate the participants' depression levels before and after the intervention.

Music pieces: Music pieces preselected according to the participants' music preferences should be used in the intervention.

Intervention

The musical neurofeedback intervention involves 10–15 sessions (ideally two sessions per week) of 15–20 min each. Participants listen to music pieces selected according to their music preferences and are encouraged to increase the loudness and tempo of the pieces based on their arousal and valence levels. The neurofeedback system is tuned so that increased arousal, computed as beta-to-alpha activity ratio in the frontal cortex, corresponds to increased loudness, and increased valence, computed as relative frontal alpha activity in the right lobe compared to the left lobe, corresponds to increased tempo.

Evaluation

The Beck Depression Inventory (BDI) is used to assess the severity of depression pre- and post-intervention. Additionally, EEG data may be collected using the EEG device at pre- and post-intervention, and statistical analysis may be performed to determine the significance of the changes in the EEG data.

Procedure

* Participants are selected based on the inclusion and exclusion criteria.
* Informed consent is obtained from each participant.
* Pre-intervention evaluation is conducted using the BDI and EEG data.
* Participants undergo 10–15 sessions of musical neurofeedback intervention.
* Post-intervention evaluation is conducted using the BDI and EEG data.

Expected Outcomes
It is expected to see a significant improvement in the BDI scores and a decrease in relative alpha activity in the left frontal lobe of the participants.

5.5 Chapter Summary

This chapter delves into the potential benefits of integrating three approaches: music therapy, neurofeedback, and emotion detection, with the aim of improving the mental health of elderly individuals. To achieve this, a novel music neurofeedback approach is presented, which enables patients to control expressive parameters of music pieces through their emotional state, as decoded from their brain activity. The primary focus of the chapter is to showcase the application of music neurofeedback as an effective intervention for alleviating depression in elderly individuals. The results of the study showed an improvement in the depression scores of the participants and a significant decrease in relative alpha activity in their left frontal lobe, which can be interpreted as an improvement in their depression condition. Finally, the chapter concludes by outlining a music-based neurofeedback intervention protocol for depression treatment, providing a framework that can be adapted and implemented to improve the mental health of elderly individuals.

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Chapter 6
Emotions and Music in *Palliative Care*

Contents

6.1 Palliative Care

In 2008, the World Health Organization defined palliative care as "an approach that improves the quality of life of patients and their families facing the problems associated with life-threatening illness, through the prevention and relief of suffering by means of early identification and impeccable assessment and treatment of pain and other problems, physical, psychosocial and spiritual." It is an interdisciplinary approach to specialized medical and nursing care for individuals with life-limiting illnesses. It focuses on providing relief from the symptoms, pain, and psychological stress of a serious illness, regardless of diagnosis. The goal is to improve the quality of life for both the patient and the family. Historically, palliative care emerged as a response to the needs of the terminally ill, primarily cancer patients. Dame Cicely Saunders, often considered the founder of the modern hospice movement, established the first hospice centre, St. Christopher's Hospice, in the United Kingdom in 1967. The movement sought to address the unmet needs of patients facing the end of life, emphasizing comfort, dignity, and quality of remaining life.

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Palliative care, as a holistic approach, underscores the importance of treating the person rather than just the disease. With its patient and family-centred focus, it bridges the often-existing gap between medical interventions and quality, compassionate care. As medical advancements increase the life span and change the nature of life-limiting diseases, the role of palliative care becomes even more critical. Ensuring its understanding, accessibility, and integration into the broader healthcare system is imperative for the modern era.

6.2 Music and Palliative Care

Helping patients in palliative care and their families to cope effectively with the pain, worries, and emotional impact inherent in the diagnosis of terminal illnesses is a recurrent challenge for doctors and nurses in palliative units. In this context, music therapy may be considered a candidate for helping to cope and provide emotional and physical comfort to patients and their families. Active music therapy (for instance, interactive live music performances) delivered by trained music therapists using singing voice and musical instruments can engage patients in ways that receptive music therapy (e.g. pre-recorded music) cannot (Standley 1986; Standley and Hanser 1995). Studies have found that live music is more effective than pre-recorded music with adult cancer patients, i.e. patients over 17 years old (MacGill 1983). Live MT allows for personalized interactions which may be particularly important for patients who relate best to music which is relevant to their special current situation (Stecher et al. 1972). In clinical palliative care, where the patient's medical condition is not likely to be improved, the objective of MT is often to improve the patient's quality of life, e.g. the improvement of pain, stress, and help to regulate negative emotions, e.g. depression, anxiety, anger (Planas et al. 2015), as well as to enhance communication (Warth et al. 2014). MT has been associated with a reduction of anxiety (Nguyen 2003; Horne-Thompson and Grocke 2008) and pain (Krout 2001; Lee 2005; Curtis 2011; Gutgsell et al. 2013), in addition to enhancing communication (Brown 2006) and spiritual well-being (Wlodarczyk 2007). Hilliard (2003) reported a significant improvement in quality of life in terminally ill patients using MT compared to standard medical care only. Nakayama et al. (2009) reported a decrease in salivary cortisol levels after nine participants received a receptive MT session. Furthermore, MT has been found not only useful for end-of-life patients but also for family and caregivers (O'Callaghan 2009). However, current reviews consistently state that there is a lack of rigorous studies providing quantitative grounds for recommending or not the use of MT in the context of palliative care (Korczak et al. 2013; Bradt and Dileo 2014). The 2010 Cochrane Review on MT clinical interventions in palliative care reported that only five trials had implemented (quasi-) randomized controlled designs (Bradt and Dileo 2014).

Recently, the neural correlates of music-evoked emotion have been investigated by the neuroscientific community using both functional magnetic resonance imaging and electroencephalography (EEG) techniques. In particular, EEG brain activity information has been used to detect emotional states in humans (Choppin 2000; Takahashi 2004; Bos 2007; Lin et al. 2010; Ramirez and Vamvakousis 2012). Patterns of EEG activity have been found to distinguish emotions induced by stimuli with different valence and arousal levels. Asymmetry patterns in frontal EEG activity have been found to distinguish between positive and negative valence, and patterns of overall frontal EEG activity have been found to identify high and low arousal levels (Schmidt and Trainor 2001; Ramirez and Vamvakousis 2012). Ramirez et al. (2015) have described an approach to computing in real-time continuous arousal and valence values from EEG activity: Based on the EEG signal of a person, the arousal level was determined by computing the ratio of the beta (12–28 Hz) and alpha (8–12 Hz) brainwaves in the prefrontal cortex, while valence values were computed by comparing the alpha power activation levels of the left and right cortical hemispheres.

In this chapter, we describe a study which contributes to the understanding of the emotional effect (estimated by EEG information) of MT in the context of palliative care. More precisely, the study aims to evaluate the effectiveness of a particular MT intervention (a 30-min session including active and receptive MT techniques) for improving the emotional state (e.g. stress, anxiety, anger, and depression) of palliative care patients by analysing their EEG activity. The patients' emotional states were estimated before, during, and after MT sessions in order to evaluate the general emotional effect of the MT session and to assess the emotional effect of particular (active and receptive) MT techniques. With this aim, 40 patients were randomized and assigned to two groups: the first group, the experimental group (EG), participated in an MT session, while the second (control) group was provided with company. The EEG-based estimated emotional state effects of MT on participants in the EG were compared with the effects of the company on participants in the control group (CG). This study represents the first clinical randomized controlled trial to examine the emotional effects of MT in palliative care using brain activity information.

6.3 Research: Emotions and Music Therapy in Palliative Care – An EEG Study

6.3.1 Participants

The research reported in this chapter is the result of a collaboration between the palliative care unit (PCU), Oncology Service, Parc de Salut Mar in Barcelona, and the Universitat Pompeu Fabra, Barcelona, Spain. Recruitment, interventions, and data collection were carried out at the PCU. Data processing and analysis were carried out at the Universitat Pompeu Fabra. All patients were assessed for eligibility according to predefined inclusion and exclusion criteria shown in Table 6.1. Forty adults (13 females and 27 males, mean = 69 years old, SD = 15) with normal

Table 6.1 Patients' inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Admitted to palliative care Advanced cancer Understanding of Spanish or Catalan language	Agony phase (no responsiveness) Cognitive impairment Deafness Restlessness and agitation

hearing participated in the study of which 20 were randomly selected to participate in an MT intervention consisting of both active and receptive techniques, and the other 20 participants were provided with company by the music therapists, but no music was involved in their sessions. Patients were randomly assigned to the MT group or to the company group by using the method of randomly permuted blocks. Participants granted their written consent, and the study procedures were positively evaluated by the Clinical Research Ethical Committee of the Parc de Salut Mar (CEIC-Parc de Salut Mar), Barcelona, Spain. All participants were patients admitted to the PCU.

6.3.2 Materials

Music Material Prior to the MT session, participants in the EG were interviewed about their music preferences in order to identify particular pieces to be included in their MT session. Music included both instrumental and vocal pieces in a variety of music genres (both classical and popular music), e.g. Canon de Pachelbel, La Bella Lola, Rien de rien, Hey Jude, and Color Esperanza.

Data Acquisition and Processing Brain activity data were acquired in the same manner as described in Chap. 3: The Emotiv EPOC EEG system (Emotiv 2014; Badcock et al. 2013) was used for the acquisition of EEG data.

6.3.3 Methods

Patients eligible for inclusion in the study were contacted at the palliative care unit (PCU), Oncology Service, and informed about the procedures and objectives of the study. Patients received no information about which of the two interventions was the actual experimental condition. If patients agreed to participate, they were asked to sign the informed consent form. Participants were treated individually. Participants in the EG received an MT session of approximately 30 min. The sessions were conducted by three professional music therapists with extensive experience in palliative care. Each MT session consisted of a receptive song, an active song, and a relaxation/imaginative receptive intervention. EEG data was recorded before the MT session, during the session, and at the end of the session. Participants in the CG

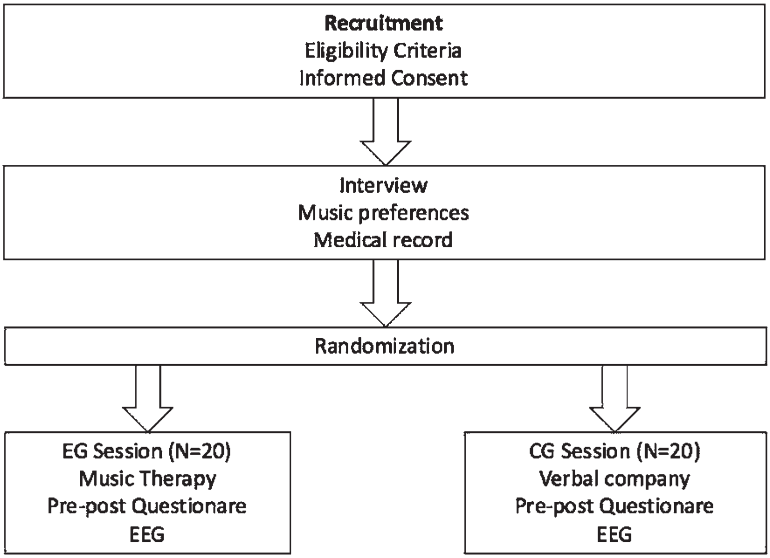

Fig. 6.1 Flow diagram of the study design

were accompanied by the same music therapists for approximately 30 min in which they conversed freely about music and their music preferences. All participants received similar levels of medication at the moment of the study. Figure 6.1 shows a flow diagram of the study design.

Similarly to the data analysis in Chap. 3, the patients' EEG data were transformed into a coordinate in Thayer's arousal–valence emotion plane (Thayer 1989), following the approach by Ramirez and Vamvakousis (2012). Artefact detection/elimination was performed by visual inspection of the signal. EEG data were normalized to avoid inter-participant variability. Using the EEG signal of a participant, the arousal level was computed as the ratio of the beta (12–28 Hz) and alpha (8–12 Hz) brainwaves (see Eq. 3.1 in Chap. 3) recorded in four locations in the prefrontal cortex: AF3, AF4, F3, and F4 (see Fig. 3.1 in Chap. 3). Valence values were obtained by computing the difference of alpha power in channels F4 and F3 (see Eq. 3.2 in Chap. 3).

6.3.4 Results

Among the symptoms assessed with Edmonton Symptom Assessment System (ESAS), tiredness ($p = 0.002$), anxiety ($p = 0.002$), breathing difficulty ($p = 0.042$), and well-being ($p = 0.036$) showed statistically significant improvement between pre- and post-values in the EG. No statistically significant differences were found in the pre- and post-values of these indicators in the CG.

Table 6.2 Average and standard deviation of arousal and valence values at the beginning and at the end of the session

Group	Indicators	Beginning		End	
		Average	SD	Average	SD
EG	Arousal	−0.30	0.25	−0.19	0.18
	Valence	−0.23	0.16	−0.08	0.17
CG	Arousal	−0.35	0.25	−0.24	0.24

Using the EEG data obtained during both the MT sessions and the company sessions, average valence and arousal values were computed at the beginning and at the end of the sessions (see Table 6.2). Average valence values in Table 6.2 correspond to the average degree of relative alpha activity in the left frontal lobe, thus larger values are associated with more positive emotional states. Average arousal values on the other hand correspond to either more beta activity or less alpha activity (or both) in the frontal lobe, and thus larger values represent higher arousal states. For the EG, the average arousal scores at the start and end of the session were −0.3 (0.25) and −0.19 (0.18), respectively. Meanwhile, the average valence scores for the start and end of the session were −0.23 (0.16) and 0.08 (0.17), respectively. For the CG, the average arousal scores at the beginning and conclusion of the session were −0.35 (0.25) and −0.24 (0.24), respectively. The valence scores, on the other hand, were −0.16 (0.38) at the start and −0.11 (0.33) at the end of the session.

In the EG, both the difference between arousal values ($p = 0.003$) and the difference between valence values ($p = 0.0004$) at the beginning and the end of the MT sessions were statistically significant. No significant differences were found in the CG.

Figure 6.2 shows the correlation within a session between time and the computed average arousal (orange line) and valence (blue line) values, for the EG. Periods in time correspond to each of the session sections: beginning, receptive song, active song, receptive imaginative intervention, and end of session. For arousal, the obtained correlation was $r = 0.63$ ($p = 0.25$), while for valence it was $r = 0.89$ ($p = 0.04$).

Figure 6.3 shows the plot in the arousal/valence plane for the averaged estimated emotional state of participants in the EG during the music therapy session: (1) initial state, (2) receptive song, (3) active song, (4) receptive imaginative intervention, and (5) final state.

Discussion

Analysis of the qualitative self-reported data showed that 12 out of the 20 participants in the EG reported feeling less weak after the MT session compared with the beginning of the session (while none of the other participants in the group reported increased weakness), confirming the reported statistically significant difference ($p = 0.002$) between pre- and post-weakness self-reported values. On the other hand, 6 out of the 20 participants in the CG reported feeling weaker after the company session (while only two reported feeling less weak). Similarly, 11 out of the 20 participants in the EG reported feeling less anxious, and 12 were in a better mood

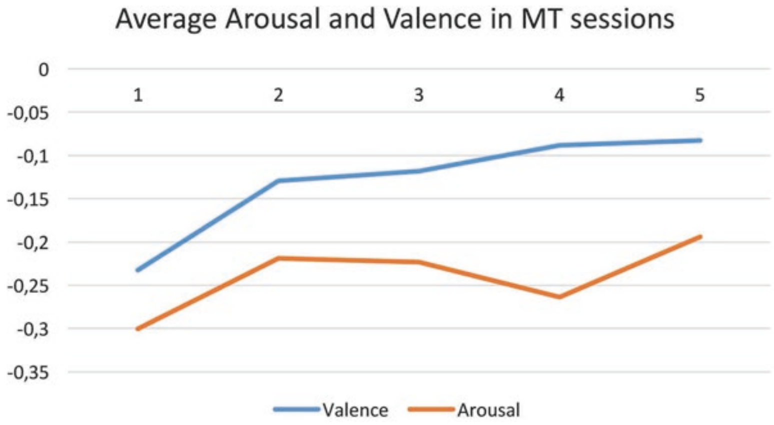

Fig. 6.2 The experimental group averaged arousal (orange) and valence (blue) levels over time. 1 = beginning, 2 = receptive song, 3 = active song, 4 = receptive imaginative intervention, and 5 = end of session

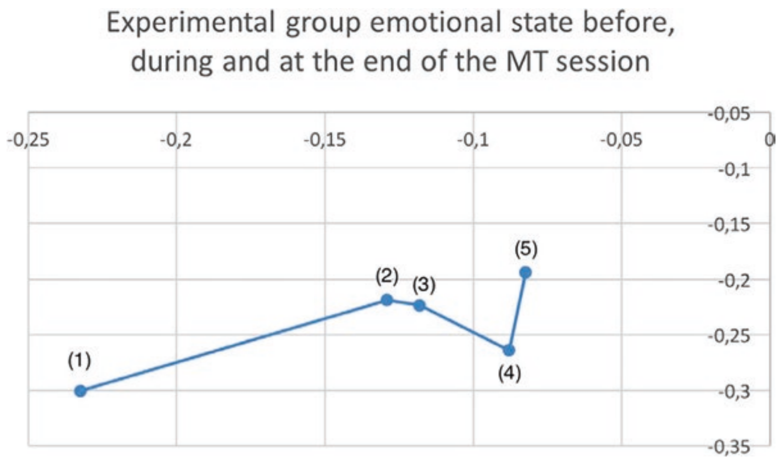

Fig. 6.3 Plot in the arousal/valence plane for the averaged estimated emotional state of participants in the EG during one session: (1) initial state, (2) receptive song, (3) active song, (4) receptive imaginative intervention, and (5) final state

after the MT session compared to their self-reported values at the beginning of the session. This is in line with the statistically significant decrease in anxiety ($p = 0.002$) and increase in mood ($p = 0.036$).

Electroencephalography data obtained showed that the overall valence level of the participants in the EG was significantly higher at the end of the MT session compared to the starting level ($p = 0.0004$). This was not the case in the CG where no significant difference in valence levels was found. This result should be interpreted as a decrease of relative alpha activity in the left frontal lobe in the EG participants, which may be interpreted as an improvement of mood or a lessening of depressive mood (Henriques and Davidson 1991; Gotlib et al. 1999; Ramirez et al. 2015). This reinforces the significant improvement results in self-assessment mood reported by the participants in the EG. Similarly, arousal values at the beginning and at the end of the MT session showed a smaller but nevertheless significant difference ($p = 0.003$) in the EG, while no difference in arousal values was found in the CG. The lower p-value for arousal may be due to the fact that while most of the patients with terminal cancer are naturally in a low arousal state (e.g. low mood or depressed), there may be some patients who feel anxious, i.e. are already in a high arousal state. EEG data also showed a significant improvement in valence in participants in the EG, reflecting a positive change in their initial emotional state. It is worth noting that while there was a continuous improvement in the participants' valence throughout the whole MT session, the first MT intervention (i.e. the receptive song) alone produced a significant improvement in valence ($p = 0.0019$) when compared to the EG participants' initial state.

Regarding the relative effects of the different MT techniques applied during the session (i.e. passive listening, active listening, and relaxation), relaxation produced significantly lower arousal levels than active listening in participants in the EG ($p = 0.025$). This result was expected since the relaxation technique is normally used for managing both psychologically and physiologically agitated states. Surprisingly, no similar significant differences were found between relaxation and passive listening. No relatively significant differences in valence were found between passive listening, active listening, and relaxation.

In the EG, no significant correlation between arousal values and time was found. This may be because of differences between the participants' states of arousal, as previously mentioned, to the different MT techniques used in the sessions, or the differences between participants' sensitivity to music. Interestingly, the correlation between computed valence levels and time within the MT session was found significant ($p = 0.038$), which represents a gradual and constant improvement in the EG participants' valence emotional state. It has to be noted that the time and type of MT intervention are confounded, thus this result has to be investigated further in order to establish if it is due to the natural progression of the MT session or to the particular sequence of interventions.

Considering the observed improvements in valence levels in one MT session and the limited duration of each session (i.e. approximately 30 min), it seems possible that further improvement in valence levels may have been obtained if sessions had been longer and/or if treatment had consisted of more sessions. Unfortunately, due to the very short lifespan (2 weeks on average) of the participants in the study, it was impossible to program more than one MT session per participant. In the past, only a few studies in the literature have investigated the long-term effect of MT. In the current study, no follow-up of the participants in order to examine the long-term effect of MT was possible. We plan to investigate this issue further, perhaps considering a different group of patients.

In summary, the results obtained in this study seem to indicate that MT techniques (both active and receptive) can be useful tools for modulating the emotional state of end-of-life patients. Helping such patients to modulate their emotions may improve their quality of life by helping them cope with the emotional effects inherent in their condition. Although this study is limited in scope due to the use of only one MT session per participant, it provides an evidence-based rationale for MT in palliative care based on methods involving brain activity (EEG) data. Furthermore, the results obtained open the possibility for personalized MT interventions based on patients' emotional states before MT is applied.

6.4 Protocol: Music Therapy Intervention for Palliative Care Patients

The purpose of this protocol is to apply music therapy (MT) and evaluate its effectiveness in improving the emotional state and physiological symptoms of palliative care patients. The protocol is grounded on the results of the study described earlier in this chapter at the palliative care unit (PCU), Oncology Service, Parc de Salut Mar.

Inclusion criteria: Patients who are receiving palliative care and who are able to provide informed consent are eligible to participate in the study.

Exclusion criteria: Patients in the agony phase, with cognitive impairment, with deafness, or who are restless or agitated.

Methodology

- Participants will be informed about the procedures and objectives of the intervention and will sign the informed consent form.
- Before the intervention, participants will complete the Edmonton Symptom Assessment System (ESAS). In addition to the nine symptoms considered in ESAS which are pain, tiredness, nausea, depression, anxiety, drowsiness, appetite, well-being, and shortness of breath, patients will give a self-report of their arousal and valence states. The degree of severity of each symptom/state is rated on a 0–10 numerical scale.
- Participants will receive a 30-min MT session conducted by one or more professional music therapists with experience in palliative care. The MT session may consist of a receptive song, an active song, and a relaxation/imaginative receptive intervention. Depending on the initial emotional state of the patient, the music therapist may focus more on a particular technique as follows:
  - For patients with low arousal states, for instance, depression states: focus on active song and receptive song interventions.
  - For patients with high arousal states, for instance, anxious states: focus on relaxation/imaginative receptive intervention and receptive song.
- After the intervention, participants will complete the Edmonton Symptom Assessment System (ESAS), as well as their self-reported arousal and valence levels.

- Obtained (pre- and post-) ESAS data and self-reported arousal and valence levels will be analysed to determine statistical significance.

Outcome Measures

The primary outcome measure will be the difference between pre- and post-ESAS scores and arousal and valence levels. Secondary outcome measures will include music therapist observations and subjective reports of symptom relief.

This clinical protocol aims to improve the emotional state and physiological symptoms of palliative care patients and provide evidence for the effectiveness of MT as a palliative care intervention. The intervention will contribute to the understanding of how MT can improve the emotional state and the subjective and physiological symptoms of palliative care patients.

6.5 Chapter Summary

This chapter explores the benefits of music therapy to improve the emotional state and physiological symptoms of palliative care patients. We present the findings of a randomized controlled trial aimed at evaluating the impact of music therapy (MT) on terminally ill cancer patients' emotional responses. EEG-based emotion detection techniques were employed to extract instantaneous emotional indicators from the patients' brain activity data. These indicators, in the form of a coordinate in the arousal–valence plane, were analysed to quantify the overall emotional effect of MT on the patients, as well as the relative effect of different MT techniques used during the intervention. Our results showed a significant increase in positivity and arousal among the intervention group, while no significant changes were observed in the control group. These findings suggest a positive emotional effect of MT in palliative care patients. Building upon these results, we propose a music-based intervention protocol to improve the well-being of patients in palliative care.

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Chapter 7
Personalizing Music Interventions

Contents

7.1 Personalized Music Interventions

Personalized medicine (Schilsky 2010; Mishra et al. 2019) represents an innovative approach towards comprehending health, disease, and treatment results by considering an individual's unique personal data. This encompasses a broad range of information, such as medical diagnoses, laboratory studies, imaging data, environmental influences, cultural factors, and lifestyle choices. By integrating and analysing these personal factors, personalized medicine aims to tailor healthcare strategies and interventions to meet the specific needs of each individual. Despite the increasing prevalence of personalized medicine in various medical fields, its application has not yet been widely adopted in the field of music therapy.

In music therapy (AMTA 2017), the emergence of personalized medicine holds great promise in advancing our understanding and improving music-based interventions. It offers the potential for enhanced and improved music-based treatments, leading to better long-term health outcomes. Recent advancements in off-the-shelf sensing technologies, cloud infrastructure, imaging technologies, and other fields enable the collection of comprehensive multimodal information from individuals. However, as in other medical fields, these remarkable innovations in sensing and treatment capabilities also generate a substantial amount of personal data for each patient, raising important considerations regarding data privacy and management.

R. Ramirez-Melendez, *Neurocognitive Music Therapy*,
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The collection and computational processing of multimodal information from patients present ongoing challenges in terms of both cost and technical complexity. However, as the costs of data acquisition devices decrease, the cost and effort for data collection are reduced. This advancement will provide valuable insights into the dynamic nature of an individual's clinical condition. One of the primary obstacles in this field is the scarcity of high-dimensional data samples, but this can be addressed through cost reduction, improved technology accessibility, and a continued commitment to open science, including the deposition of new data into public repositories. As we gain access to these new data, there is a pressing need to develop complementary methods to effectively analyse and interpret them. Artificial Intelligence (AI) methods can play a crucial role in enabling more data-driven approaches rather than being solely hypothesis-driven. Artificial intelligence techniques are capable of finding subtle relationships and patterns among complex multimodal data. In the case of music-based interventions, these data may include audio, video, physiological data, and medical records. AI may be an invaluable tool to decode and understand the subtle patterns among these kinds of data.

7.2 What Is Artificial Intelligence?

Artificial intelligence (AI), its related technology, and machine learning (ML) are increasingly pervasive in almost all sectors, including music, arts, society, and healthcare. These transformative technologies are revolutionizing most areas of our lives and have the potential to revolutionize patient care and healthcare organizations. The widespread use of wearable sensors presents a unique opportunity to monitor individuals' physiology, generating an unprecedented amount of personalized data in real-world settings. Advances in AI/ML algorithms have made it possible to analyse this vast amount of data, often referred to as "big data". Machine learning, a subset of AI, has gained popularity in recent decades due to advancements in computing power, making previously inaccessible methods now within practical reach. ML automates the process of building analytical models and enables the recognition of patterns in data without explicit programming for a specific task. While many of today's most effective ML algorithms were developed over half a century ago, the data and computational resources required to make them practical and feasible were previously unavailable.

Machine learning (ML) offers numerous advantages, including adaptability, scalability, automation, and the ability to leverage multidimensional and multimodal data for discovering new insights. Most common ML algorithms can be categorized into two main types of learning: supervised and unsupervised. Among these, supervised learning is the most commonly employed due to its predictive capabilities. In supervised learning, the algorithm aims to learn the relationship between a known prediction target value, for instance, the outcome of a music therapy intervention, and other variables, often easier to measure. For instance, one might seek to predict the type of musical intervention based on the patient's emotional state and clinical information. Supervised learning can be further divided into regression (for continuous target variables, like arousal level) or classification (for discrete target variables, like the positive or negative outcome after an intervention) tasks. The methods used in supervised learning encompass a wide range, from simple linear regression to advanced techniques such as deep neural networks. Simpler methods are often preferred due to their ease of understanding and better generalization capabilities. Unsupervised learning is employed when the goal is to discover groups or patterns in data without a clear outcome of interest or when the labels are unknown. For instance, we may be interested in finding groups or clusters of patients who are similar according to some criteria. This type of learning involves techniques such as clustering. Sometimes, semi-supervised learning is utilized when only a portion of the data has known labels.

Numerous research studies have indicated that machine learning (ML), particularly deep learning (DL) models, can match or even surpass human performance in crucial healthcare tasks such as disease diagnosis and interpreting medical images. However, it is important to note that AI technologies are most effective when used to enhance human efforts rather than replace them entirely. AI can minimize human errors, expand knowledge capacity, and free up time by handling repetitive tasks. Nonetheless, we must carefully consider the potential, challenges, and specific concerns related to healthcare before implementing these tools and models in clinical decision support systems.

7.3 Analysing Music-Based Interventions in Palliative Care with Machine Learning

In Chap. 6, we described a study assessing the emotional response of terminally ill cancer patients to a music therapy (MT) intervention. Based on EEG-based emotion detection techniques, instantaneous emotional indicators in the form of a coordinate in the arousal–valence plane were extracted from the patient's brain activity data. The emotional indicators were analysed in order to quantify the overall emotional effect of MT on the patients as well as the relative effect of the different MT techniques applied during the MT intervention. Overall, the music-based intervention produced a significant increase in valence and arousal.

In this context, we can ask ourselves several questions related to the personalization of the music-based intervention:

- By only considering the patient's initial emotional state, can we predict the intervention outcome in terms of emotional state?
- By considering other information on the patient's (self-assessed) physical condition in addition to the initial emotional state, can we improve the prediction accuracy of the intervention outcome?
- Can we determine which music therapy technique (from a set of possible relevant techniques) is likely to achieve the best result for a given patient? In other

words, is it possible to personalize the music-based intervention in order to maximize the benefit of the session according to some pre-established therapeutic goal?

In order to investigate these questions, we applied machine learning techniques to obtain computational predictive models.

For investigating the first question, we trained a supervised regression model to predict the final emotional state of participants given their initial emotional state. Pearson correlation coefficients of the predicted end-of-session values with respect to the true end-of-session values were computed (using tenfold cross-validation) and obtained $r = 0.53$ for arousal and $r = 0.77$ for valence. It is worth noting that the study also involved a control group not receiving music therapy, and when we applied the same methodology for this group, we obtained correlations $r = -0.15$ for arousal and $r = 0.13$ for valence. These results indicate that there is a moderate/strong relationship between the initial and final arousal/valence states of participants receiving music therapy, while there is no such relationship in the control group. In the context of this study, the results show that it is possible to predict with acceptable accuracy the final emotional state of a person after the music therapy session based on their initial emotional state. That is, using the EEG data of the participants in the study, it is possible to extract patterns which allow us to predict the emotional outcome (in particular valence) of new participants after the MT intervention. This is quite remarkable since the only input for the prediction is the emotional state of the person, characterized by arousal and valence levels.

For investigating the second question, we trained a predictive model this time adding information about the patient's physical condition characterized by self-reports of levels of pain, tiredness, nausea, depression, anxiety, drowsiness, appetite, well-being, and shortness of breath (Bruera et al. 1991; Bruera and Macdonald 1993; Chang et al. 2000). The resulting Pearson correlation coefficients of the predicted end-of-session values with respect to the true end-of-session values were $r = 0.58$ for arousal and $r = 0.84$ for valence (using tenfold cross-validation). Adding extra information about the patients improved the prediction accuracy of the model, although not dramatically. This may seem to indicate that, in the context of the music therapy sessions conducted in palliative care, most of the information relevant to predicting the emotional outcome of a session is the actual patients' emotional state information. This may be due to the reasonable assumption that there is a correlation between the physical information and the initial emotional state of a patient.

In an attempt to personalize the music-based intervention by determining the optimal music therapy technique, active, passive, or visualization, for a particular patient, we trained three models, one for each MT technique, to predict the emotional response of participants by a given technique based on their emotional state before the technique was applied. In other words, we trained different models predicting the relative emotional effect of each technique taking into account the patients' state preceding the technique intervention. The resulting Pearson correlation coefficients of the predicted emotional state after the active, passive, and visualization technique were applied with respect to the actual observed values were $r = 0.67$, $r = 0.7$, and $r = 0.77$ for arousal and $r = 0.83$, $r = 0.8$, and $r = 85$ for valence, respectively.

These models can potentially be used to personalize the kind of music therapy intervention a patient would benefit most from. The predictive models can be a tool for music therapists to anticipate the patients' response to particular music-based interventions and opt for the ones recommended by the model predictions. However, it has to be noted that using a small amount of data about music therapy effects (as in the case of this study) for training a machine learning model cannot provide definitive evidence for the predicted effects. This is due to several reasons. Firstly, limited data samples may not adequately capture the full range of variables and nuances involved in music therapy. The effectiveness of music therapy is influenced by various factors such as individual preferences, cultural background, and specific therapeutic goals, which can differ widely among participants. Without a diverse and comprehensive dataset, the machine learning model may not accurately capture the complexity and variability of music therapy effects.

Secondly, the quality and reliability of the small amount of data can be questionable. Small sample sizes and limited data sources may result in biased or unreliable information. The data may not adequately represent the diversity of participants, and there may be confounding variables that are not adequately accounted for. This can lead to misleading conclusions and inaccurate predictions of beneficial effects.

Additionally, the dynamic nature of music therapy and individual responses to treatment requires continuous monitoring and assessment. Scarce data points may not capture the long-term effects or changes that occur over time. Music therapy effects can be highly subjective and context dependent, and relying solely on limited data for training a machine learning model may overlook important individual variations and nuances. Drawing definitive conclusions based on limited data can lead to premature generalizations.

Despite these challenges and limitations, it is still crucial to strive to collect data and train predictive models to predict the effects of music therapy sessions in order to personalize therapies. Personalization is an important aspect of providing effective and tailored interventions to individuals, and predictive models can offer valuable insights and guidance in this process.

By training predictive models, we can explore the potential relationships and patterns within the available data, even if it is scarce. While the results may not be definitive evidence, they can serve as a starting point for understanding potential trends and associations between music therapy interventions and their outcomes. This initial exploration can help identify potential areas of focus and guide further research in the field.

Personalizing music therapy based on predictive models can lead to several benefits. It allows for the customization of intervention plans based on an individual's specific needs, preferences, and goals. By understanding the potential effects of different interventions, therapists can make more informed decisions and optimize the therapy experience for each individual. This personalization can enhance the effectiveness and efficiency of music therapy, potentially leading to better outcomes and improved well-being for the recipients.

Moreover, training predictive models in music therapy contributes to the advancement of the field as a whole. It encourages the collection and analysis of relevant data, promoting research and innovation. As more data become available and models are continuously refined, the predictive capabilities of these models can improve, leading to more accurate and reliable predictions.

Furthermore, the process of training predictive models in music therapy can shed light on the complexity and variability of therapeutic effects. It highlights the need for rigorous research methodologies, diverse datasets, and comprehensive evaluation. This can drive the development of standardized protocols, data collection practices, and outcome measures, ultimately enhancing the scientific rigour and credibility of music therapy as a discipline.

In summary, while acknowledging the limitations, training predictive models for predicting the effects of music therapy sessions is important for personalizing therapies. It enables customization, optimization, and informed decision-making, leading to better outcomes for individuals. It also contributes to the advancement of the field and promotes research and innovation. By continuously refining these models and incorporating more comprehensive and diverse data, we can strive towards more effective and personalized music therapy interventions.

7.4 Chapter Summary

In this chapter, we emphasize the importance of collecting data and training predictive models to predict the effects of music therapy sessions for personalized therapies. Personalization plays a vital role in delivering effective and tailored interventions to individuals, and predictive models serve as valuable tools in this process. By training these models, we can uncover potential relationships and patterns within the available data, despite the acknowledged limitations. Training predictive models for music therapy enables customization, optimization, and informed decision-making, ultimately leading to better outcomes for individuals. The chapter illustrates how machine learning may be applied for personalizing music therapy interventions by training predictive models using data obtained from the study detailed in Chap. 6.

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Index

R. Ramirez-Melendez, *Neurocognitive Music Therapy*,
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