The Leap Motion Controller in Clinical Music Therapy
A Computer-based Approach to Intellectual and Motor Disabilities

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Abstract: This paper describes a technological approach to overcome motor and intellectual disabilities through musical expression. In the context of clinical music-therapy sessions, we propose the introduction of ad-hoc hardware sensor devices to improve free-hand interaction and to foster the development of communication and motor skills. Multiple educational aspects are involved, ranging from the ability for the disabled to play together in a non-competitive environment to the achievement of tangible rehabilitation results. The proposed system captures user's gesture through a Leap Motion controller, and the signals thus generated are sent to a software tool that converts movements into music notes. These activities have been integrated into music-therapy sessions held at a renowned rehabilitation center and successfully experimented on a control group.

1 INTRODUCTION

The development of suitable computer-based technologies may help people with serious disabilities communicate and control the surrounding environment by using alternative interfaces. Technological advances can greatly improve the quality of life by providing access to work and entertainment activities.

Scientific research has clearly identified the importance of music in the physical and intellectual rehabilitation of disabled people. In this sense, it is worth mentioning some works that investigate the relationship between music and disability in history, society, and culture, such as (Lerner and Straus, 2006), (Lubet, 2011), and (Straus, 2011).

From an educational point of view, practicing a musical instrument presents many challenges: it requires manual and listening skills, as well as the ability to face the threats typical of a learning environment, such as focusing on a performance goal, gathering feedbacks to improve performance, reinforcing self-confidence, and developing a psychological and behavioral toolkit against pressure and problems (Martin, 2008). This is particularly true when working with people with disabilities, due to their physical and intellectual impairment. As clearly stated in (Ludovico and Mangione, 2014), ad hoc music learning environments can foster self-regulation abilities in students, by covering a 3-phase cyclical process: fore-thought, performance or volitional control, and self-reflection (McPherson and Renwick, 2001).

The mentioned aspects, which involve self-awareness and encourage self-improvement, are crucial factors in the design and implementation of interfaces to let people actively join music experiences; but, despite the increasing number of enabling technologies and support tools, the access to music performance and creation still presents many obstacles for people with physical and intellectual disabilities.

In literature, the term *enabling technology* designates a technology that alleviates the impact of disease or disability. According to (Hansson, 2007), 4 categories can be recognized, according to how their impact is distributed between the individual and the surrounding society: 1. therapeutic (restoring the original biological function that has been lost or preventing further losses), 2. compensatory (replacing, fully or partially, a lost biological function by a new function of a general nature), 3. assistive (allowing to perform a task or activity despite an uncompensated disability or lack of function), and 4. universal (i.e., intended for general use) technology.

A recent device able to cover multiple categories of enabling technology is the Leap Motion controller. First released in 2012, it is a computer hardware sensor device able to track hand and finger motions as input, requiring no hand contact or touching. This USB peripheral device was originally designed to be

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Figure 1: The Leap Motion controller.

Figure 2: A software application that shows hand and finger tracking by the Leap Motion.

placed on a physical desktop, facing upward (see Figure 1). Using two monochromatic IR cameras and three infrared LEDs, the device observes a roughly hemispherical area to a distance of about 1 meter, catching about 200 frames per second. Data are sent to the host computer, where 3D position of hands and fingers are synthesized by comparing the 2D frames generated by the cameras (see Figure 2). As demonstrated by independent tests, the overall average accuracy of the controller is about 0.7 millimeters (Weichert et al., 2013).

Thanks to its intrinsic characteristics, the Leap Motion controller has been already adopted in a number of medical and therapeutic applications. Often, this tool is used to allow free-hand interaction in the treatment of physical injuries, including applications for hand rehabilitation (Liu et al., 2015; Taylor and Curran, 2015), gesture recognition to recover the functionalities of upper extremity (Gieser et al., 2015), and stroke rehabilitation (Khademi et al., 2014). Other works – e.g., (Iosa et al., 2015) and (Zhu et al., 2015) – explicitly address the possibility to treat cognitive and intellectual disabilities.

In music research the potential of the Leap Motion

to intuitively generate and/or control a performance is currently under investigation. This technology is seen as a new interface for music expression, as stated in (Ritter and Aska, 2014), and implementations embrace fields such as sound synthesis and interactive live performance (Hantrakul and Kaczmarek, 2014).

Much has been written about the sociocultural dimensions of the interface between the human body and technologies. It is worth citing (Haraway, 1991), (Penley and Ross, 1991), (Gray et al., 1995), and (Halberstam and Livingston, 1995), to name but a few. The introduction of new computer technologies such as augmented and virtual reality has risen interest in how the ontology of bodily experience and selfhood are altered via the human/machine interface (Riva et al., 2016). Conversely, the ways in which technologies can contribute to the meanings and experiences of the lived body/self with disabilities has been explored to a lesser extent (Lupton and Seymour, 2000).

The approach described below tries to draw full benefit from the features of the Leap Motion, combining its potential in the therapeutic and rehabilitative fields with the possibility for (disabled) users to intuitively control the parameters of musical expression.

In this context, the definition "computer-based education" assumes multiple meanings: on the one hand, it means employing enabling technologies to learn the use of a virtual musical instrument, on the other it involves re-education in the development or recovery of physical and intellectual abilities.

The paper is structured as follows: Section 2 will describe the clinical framework of the initiative, Section 3 will provide technical details, Section 4 will show the point of view of the music therapist, finally Section 5 will assess the experience presenting some measurable results.

2 BACKGROUND

The computer-aided therapeutic activities described in the present work were experimented – and are still ongoing – at an Italian rehabilitation center called *Sim-patia*.[1]

The mission of this social cooperative is to give disabled persons a future perspective by minimizing the effects of their handicap and promoting their autonomy. In this context, guests are invited to consider their life condition not as a situation that prejudge the

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[1]Cooperativa Sociale Sim-patia, Via G. Parini 180, 22070 Valmorea (CO), Italy, http://www.sim-patia.it/

Figure 3: Music therapy at *Sim-patia* in a "traditional" setting.

possibility of fully expressing themselves, rather as an invitation to acquire new abilities in order to achieve such a result. *Sim-patia*'s motto is: "With the disability, life just changes but it does not finish".

Guests are stimulated to exploit their potential and skills, even in highly compromised situations, in order to develop communication and motor autonomy to be spent in everyday life. This goal is achieved by advanced technological solutions, specific equipment to meet individual needs (e.g., special keyboards, bone-conduction headphones, eye-gaze controllers, etc.), and scientific collaborations involving specialists, academia, and research centers.

In particular, the technology center at *Sim-patia* is the area devoted to the study and realization of hi-tech solutions. Starting from the analysis of the individual needs of the disabled, a team composed by therapists, engineers and computer experts designs and develops, or adapts, devices useful for everyday house management, work, communication, and leisure time.

Sim-patia offers cognitive and logopedic therapies, manual and creative activities, virtual travels, cinema clubs, and workshops on gardening, theater, and music. As it regards the latter aspect, sound and music education plays a key role in rehabilitation. The disabled is invited to develop music-based communication skills through the interaction with the environment and non-competitive peer cooperation, in the context of group activities guided by a music therapist. Research work – such as (Karageorghis and Terry, 1997), (Scheufele, 2000), and (Schlaug et al., 2005) – studied the effects of music on the development of memory, language, rhythm, attention, sense-perceptual skills, communication, and relaxation.

A music therapy session at *Sim-patia*, like the one shown in Figure 3, is organized as follows:

- introduction to a given author or music genre pre-

viously selected by the group;
- listening activities aiming to catch the attention of the patient and create a pleasant climax;
- sound-based games;
- motor games based on sound/gesture association and expressive motion;
- rhymes, and vocal, sung, and mimed songs;
- guided relaxation.

In this framework, a scientific cooperation between *Sim-patia* and the Laboratory of Music Informatics[2] of the University of Milan originated a computer-based solution that provides or extends the interaction of disabled people with music during therapeutic sessions.

This kind of music-based rehabilitation addresses 3 groups of patients, with 8 to 10 participants per group and homogeneous for pathologies: the first group includes users with cognitive disabilities and some cases of moderate motor disability, the second group is formed by boys up to 25 years old with motor and cognitive disabilities and autism, and the third group are users in a wheelchair due to traffic accidents. The time schedule is approximatively one hour per group, repeated once a week, organized as follows: 45 minutes of practical activities plus 15 minutes of final discussion, open to educators' and patients' comments.

No patient is excluded *a priori*, but some pathologies require particular sensitivity and patience. For example, this is the case of autistic children, who need more time than others to get in touch with the setting.

3 THE PROPOSED SOLUTION

The goal of the computer-based application is to let patients generate music (in terms of pitch and rhythm) by playing a virtual instrument in a free-hand and no-contact context. The sequence of notes provides a sort of leading voice that the music therapist accompanies with the guitar.

The overall system is composed by hardware (a computer with a Leap Motion attached) and software components (a specially designed browser application that integrates the LeapJS framework in order to communicate with the hardware device). One of the goals of the proposal was to keep both computer requirements and expenses to a minimum, so as to make the implementation simple, cost-effective, and easily reproducible in other contexts. Aside from the purchase
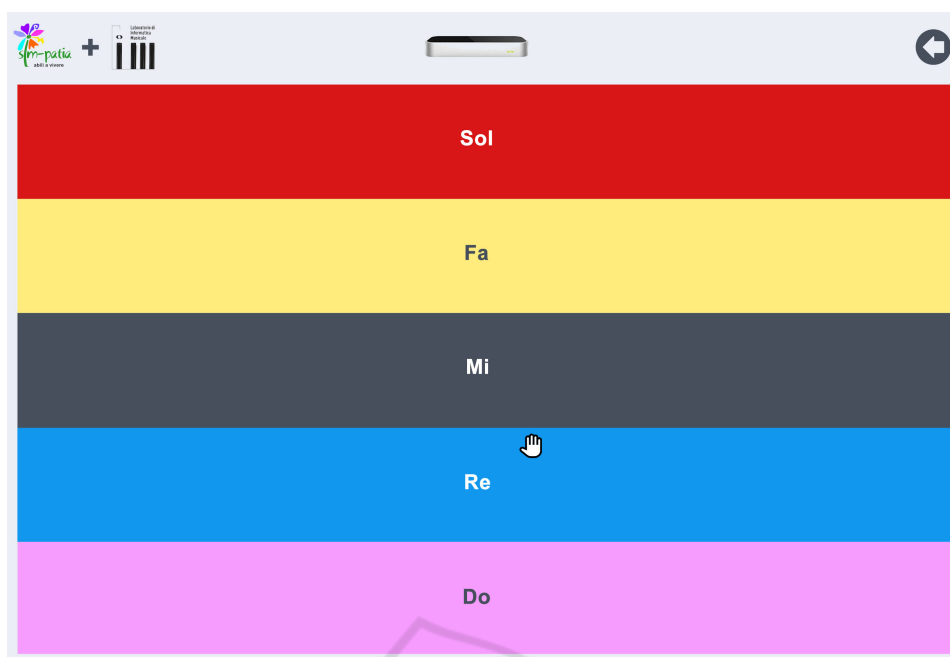
Figure 4: The main window of the browser interface. Horizontal sections can be customized in color, number and pitch association during the set-up phase. The cursor provides a feedback on the current hand position.

of the controller, which is anyway a low-cost device,[3] the other requirements can be easily fulfilled.

The browser application allows users to play a virtual musical instrument with a hand movement from the bottom up and vice versa, providing a graphical feedback of the relative position of the hand. The space above the controller is vertically segmented into a number of rectangular areas, each one referring to a different note pitch and represented on screen through a colored section (see Figure 4). When the distance between hand and controller exceeds a threshold value, this gesture triggers the production of a new sound. If the hand remains in a given area for a predefined amount of time, a new note with the same pitch is performed.

User interaction is deliberately simple, so as to respond to the constraints posed by the clinical situation of seriously disabled people. For example, the horizontal position of the hand could ba tracked as well, but we decided to ignore data on this axis. If the therapist should decide to detect horizontal movements instead of vertical ones, the Leap Motion could be easily rotated, and also the interface accordingly.

Some parameters can be customized during the set-up phase, in order to better meet specific needs. First, the capture range can be fine-tuned by determining the minimum and maximum distance from sen-

sors that each user can cover with his/her gestures. The declared range of the device is 25 to 600 mm, but often the movements of patients are far more limited. Moreover, configuring the actual capture area allows to place the device in non-standard position and orientation.

Another parameter that can be fixed is the number of horizontal sections the total area is divided into, or alternatively their height. This value sets the number of different pitches supported by the interface. For example, paraplegic patients as well as seriously injured people may experience great difficulty in moving the limbs and pointing precisely: in this case, it is possible to adopt a setting with few but well-defined areas. For different reasons, giving the option to perform only a limited number of notes can encourage users with intellectual disabilities, without causing them a sense of frustration.

Please note that the mentioned parametrization, basically intended to provide the user with a comfortable interface, can be also turned into an instrument of motivation and engagement. For instance, the experience described in Section 5 showed that, after an initial learning and adaptation phase, some patients were eager to play with richer and more complex configurations, implying a higher number of notes.

Other parameters customizable through the interface are less functional to rehabilitation, but they make music experience more engaging. For example, specific pitches can be associated to the horizon-

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[3]At the moment of writing, the Leap Motion controller is sold for less than $80.

tal sections, thus supporting typical progressions and cadences (e.g., the I-V or I-IV-V progression), scale models (e.g., the pentatonic or the whole tone scale), and altered notes to play in specific keys. Another option concerns the timbre of the virtual instrument in use.

The graphical interface was designed keeping simplicity in mind. Implemented as a browser application in HTML5 and JavaScript, the main page presents a number of colored horizontal sections corresponding to pitches and a hand-shaped cursor that provides visual feedback on the rough position of the hand. It would be easy to track and graphically represent further or more precise information. For instance, the Leap Motion technology can track both hands and even single finger bones, and, concerning the interface, a hand and finger 3D visualizer is already available in the extension framework called LeapJS. Nevertheless, the music therapist discouraged a finer level of granularity, considering it misleading for patients affected by intellectual disability and frustrating for those presenting physical impairment.

4 THE MUSIC THERAPIST'S POINT OF VIEW

A subjective way to evaluate the initiative was an interview with the music therapist working at *Sim-patia*, who played a key role both in the design and in the test phase of the computer-based solution (see Figure 5). Being an expert domain, his remarks will be helpful to assess the educational valence in the context of physical and intellectual stimulation of people with disabilities. A more objective way to assess the experience, based on measurable results, will be provided in Section 5.

First, the therapist motivated the design choice to map pitches onto the vertical dimension. In Western tradition, there is the cultural assumption that acute pitches "go upwards" as they are compared to light and purity, whereas low pitches are associated to darkness and gravity. Consequently, it is more intuitive for anyone – especially for a child or a person with intellectual disability – to link high and low notes to the upper and lower part of the body respectively.

Another important point to clarify is the possibility to customize the pitches that users can play. Since the interface addresses – in general – persons with no previous music training, and presenting different levels of disability, either motor/physical or cognitive/intellectual, the goal of creating melodic awareness for them is not trivial. Rather than providing

Figure 5: A disabled person interacting with the system.

users with a traditional diatonic scale (e.g., the eight-grade C major scale), the proposed virtual instrument supports (potentially) smaller sets of pitches. Even a minimal subset of natural notes – formed, e.g., by C and D – showed to be effective in producing articulated melodic events. In fact, these two pitches can be intuitively associated to the ideas of rest/conclusion and tension/suspension, also supported by the adaptive guitar accompaniment of the music therapist. After a short time, users realize that their gestures are producing something similar to a dialog.

Complexity – that implies a higher level of difficulty, but also greater expressive potential – can be raised by adding notes. As a result, patients are motivated to interact with the musical accompaniment, being rewarded by the achievement of richer melodic tunes. Interaction with external musical stimuli can be fostered also through a suitable choice of the pitch set. For instance, the pentatonic scale, presenting no halftone interval, is easily adaptable to any accompaniment, consequently it has been extensively used during music-therapy sessions.

In conclusion, during the interview the music therapist showed a high degree of appreciation towards the interface, described as an enabling device that enhances the traditional therapy sessions by encouraging the patients' interaction with music.

5 ASSESSMENT

After verifying the effectiveness of the computer-based framework from the therapist's point of view, the research questions to be answered are if and to what extent its adoption has allowed patients to progress on their rehabilitation.

The approach adopted at *Sim-patia* is based on the Phenomenological-relational Methodology by Paolo

Figure 6: Observation form in use at the Helvetic Music Institute, originally prepared by P. Cattaneo and A. Elia for experimental music therapy projects at the Case per Anziani del Canton Ticino.

Cattaneo (Cattaneo, 2009; Elia, 2017) and focuses on the centrality of musical language, that aims at the construction of the therapeutic relationship and is intended as an "active principle" linked to the cultural dimension and neurobiochemical responses.

The music therapist used an observation form (see Figure 6) to track improvements during the period of therapy. This document, compiled at the beginning and at the end of the rehabilitation path, allows to objectively evaluate the evolution occurred in the psycho-physical, affective-emotional and cognitive field, thus showing the results achieved for each participant through therapeutic intervention. The music therapist is asked to express his opinions through a 4-point Likert scale.

The principle on which the evaluation form is based takes into consideration the three main elements of musical language, i.e. *rhythm*, *melody* and *harmony*, and combines them with the three main dimensions of the human system, namely *movement*, *emotion* and *thought*. The three main areas are detailed in sub-areas that specifically describe the participant's responses to the music-therapy setting. In this experimentation, only the significant part of the form was used.

Due to the peculiar characteristics of this experiment, the therapist recorded additional data concerning the capabilities achieved across multiple sessions, i.e. the range of distances from the Leap Motion that the user was able to reach (wider ranges correspond to better motor skills) and the number of notes proposed to the patient (higher values imply a better ability to control gesture).

Concerning the range, it is worth underlining that some patients were able to cover the full interval, spanning from 25-50 to 600 millimeters. In this sense, patients with autism were particularly skilled, but – more surprisingly – also some users with motor disability were able to achieve this remarkable result.

The average number of notes proposed to users was 5, considerably above the minimum subset of 2 notes mentioned in the Section 4. This value is relevant both for people with motor disabilities, who could experience difficulties in precisely pointing an area, and for people with intellectual disabilities, less prone to interact with music.

Table 1 summarizes the results of the experimentation conducted on a group of 9 patients at *Simpatia*. The test set is heterogeneous as it regards age, genre, and pathology. The latter aspect required to customize the parameters of the interface, and specifically to calibrate gesture captures and to fix the number of playable notes. For the sake of brevity, the last column provides an average value of the multi-dimensional data from the observation form. Even if starting from different levels, the therapist registered improvements in all his patients in a very limited number of sessions. It is worth noting that: *User 3*, despite his motor disability, was able to cover the full range of distances and to play a whole 8-grade scale; *User 5*, affected by quadriplegia, obtained very encouraging results in terms of motion ability; and *User 7*, presenting autism spectrum disorder, was successfully administered a non-trivial 5-grade scale.

In general terms, making autistic patients interact with the interface and produce music together with the therapist was a remarkable success. Anyway, this category of users showed innate musical abilities, being able to easily memorize tunes and reproduce them.

6 CONCLUSIONS

In this work, we have described a computer-based approach to encourage the interaction of disabled people with music content during music-therapy sessions. Starting from educational roots and clinical requirements, with the help of experts from different domains (behavioral and rehabilitative medicine, music

Table 1: Evaluation of the results achieved through music-therapy sessions. Values in the last column are expressed – session by session – in a 4-point Likert scale.

User	Genre	Pathology	Parameters	Session	Results
1	M	Mean mental retardation, spastic hemiplegia and hemiparias at unspecified hemispherical site, predominant emotionality disorders	start = 50 mm end = 600 mm notes = 6	S1 S2 S3 S4 S5 S6	2 2 3 3 3 4
2	F	Intellectual disability with infant cerebral palsy and bilateral spastic tetrapareris	start = 25 mm end = 300 mm notes = 3	S1 S2 S3 S4	1 2 2 3
3	M	Spastic quadriplegia, severe mental retardation, dysphasia	start = 25 mm end = 600 mm notes = 8	S1 S2 S3 S4	3 3 4 4
4	M	Childhood autism with pervasive developmental disorder, moderate cognitive delay and echolalia	start = 25 mm end = 500 mm notes = 6	S1 S2 S3	2 2 3
5	M	Quadriplegia caused by street trauma	start = 50 mm end = 400 mm notes = 4	S1 S2	2 4
6	F	Motor disability	start = 100 mm end = 300 mm notes = 3	S1	2
7	M	Autism spectrum disorder	start = 25 mm end = 600 mm notes = 5	S1 S2	1 3
8	M	Brain cerebral hemorrhage with femoral fracture	start = 50 mm end = 600 mm notes = 6	S1 S2 S3	2 3 3
9	M	Autism spectrum disorder	start = 50 mm end = 600 mm notes = 4	S1 S2	1 2

and musicology, computer science) we have designed and released a framework that was tested in a clinical context, showing encouraging results.

Based on the Leap Motion, the application implements a simplified and intuitive virtual instrument that gives musically-untrained disabled people the chance to create a music tune, picking available pitches from a user-tailored set. The musical experience is highly customizable, depending not only on the type and level of disability to treat, but also on the skills and motivation developed by users during their rehabilitation path.

As a relevant result, the creation of recurrent musi-cal patterns becomes a recognizable element that triggers formal processes. Thanks to sound, the whole psychomotor sphere is stimulated: through live interaction, a gesture produces a clearly recognizable sound feedback, and the effect is the feeling to play and achieve the desired musical result, even in absence of a physical contact.

This computer-based project presented multiple educational meanings. First, thanks to the Leap Motion, disabled people were encouraged to play together in a non-competitive environment, learning music concepts intuitively (e.g., melody, rhythm, harmony, synchronization, etc.). Another form of edu-

cational achievement can be seen in the rehabilitation results fostered by this approach, which motivated users and pushed them to overcome their limits in order to reach new goals (e.g., a more precise pointing or a higher number of available notes). But another educational valence of the proposed approach emerges in a flipped context, since the therapist himself learned something about his patients from the musical interaction they were able to produce together.

Concerning future work, we plan to track patients' improvements over a longer period, extend this early experimentation to a wider test group, and propose such a computer-based solution to other therapists and rehabilitation centers.

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