The Prospects of Musical Instruments For People with Physical Disabilities

Jeppe Veirum Larsen
Institute for Architecture, Design and Media Technology
Aalborg University
Aalborg, Denmark
jvl@create.aau.dk

Dan Overholt
Institute for Architecture, Design and Media Technology
Aalborg University Copenhagen
Copenhagen, Denmark
dano@create.aau.dk

Thomas B. Moeslund
Institute for Architecture, Design and Media Technology
Aalborg University
Aalborg, Denmark
tbm@create.aau.dk

ABSTRACT
Many forms of enabling technologies exist today. While technologies aimed at enabling basic tasks in everyday life (locomotion, eating, etc.) are more common, musical instruments for people with disabilities can provide a chance for emotional enjoyment, as well as improve physical conditions through therapeutic use. The field of musical instruments for people with physical disabilities, however, is still an emerging area of research. In this article, we look at the current state of developments, including a survey of custom designed instruments, augmentations / modifications of existing instruments, music-supported therapy, and recent trends in the area. The overview is extrapolated to look at where the research is headed, providing insights for potential future work.

Author Keywords
Interactive performance systems; Interfaces for sound and music; Music and robotics; Social interaction in sound and music computing; Actuated instruments; Actuated guitar; Musical instruments for the disabled.

ACM Classification
H.5.2 [Information Interfaces and Presentation] User Interfaces --- Haptic I/O. H.5.5 [Information Interfaces and Presentation] Sound and Music Computing. K.4.2 [Social Issues] Assistive technologies for persons with disabilities.

1. INTRODUCTION
Many countries in the world today face an aging population, meaning an increase in the average age of the population in the coming years. Old age brings with it the risk of diseases and general decline in health. Therefore, rehabilitation methods are quickly becoming increasingly important. We focus here on therapy and rehabilitation methods for those affected by physical disabilities, using music as a motivational factor to incentivize user engagement with the process. Our approach has been described in [33, 34], but here we focus on the field in general – as an emerging set of techniques and technologies enabling those with physical disabilities to improve their condition, both physically and psychologically.

2. PHYSICAL DISABILITIES
A physical disability can be caused by a number of different things. It can be inherent, acquired, disease-born, or caused by an accident. We start by examining the most common causes for physical disabilities within Denmark. Here we focus only on Denmark as a sample population, due to the local availability of statistics and information available to us as researchers.

NIME'16, July 11-15, 2016, Griffith University, Brisbane, Australia.

2.1.1 Cerebral Palsy
In Denmark (population 5.6 million), about 10,000 people have been diagnosed with Cerebral Palsy (CP), with approximately 33% under 18 years old. These numbers suggest that around 2 percent every year are confirmed CP patients, or around 180 children every year [1].
Cerebral Palsy is a type of brain damage, and 90% of the cases are caused by damage or disorders to the immature brain during pregnancy. However, precisely what causes the brain damage is not clear. It can be caused by many different complications, such as infection during pregnancy, lack of oxygen, small blood clots or cerebral hemorrhages. In 10% of cases, it is estimated that injuries during birth or shortly thereafter were the cause.
There are three primary types of CP: spastic, dyskinesia, and ataxia. There is a fourth category as well, in which there is a mix of the three primary types. Spastic Cerebral Palsy is by far the most dominant type, covering 75 – 80% of the cases. In this type of CP, increased muscle tone causes stiffness in the muscles, making movements with the affected body part(s) awkward. Spastic CP is categorized by what body parts are affected. Monoplegia is when a single arm or leg is affected, diplegia is when mainly both legs are affected, hemiplegia is when one side of the body is affected, and quadriplegia, which is the most severe, means the entire body is affected. Dyskinesia CP causes uncontrollable movements, which can be either slow or rapid. Finally, ataxic CP causes problems with the coordination of the limbs.
Aside from difficulties in controlling limbs or other affected body parts, CP can also (depending of the severity or the damage) have a great impact on cognitive abilities.

2.1.2 Stroke
In Denmark, about 12,000 people per year have strokes, and about 75,000 people live with complications caused by strokes [2]. Worldwide, it is estimated that one in six people will suffer a stroke in their lifetime [3]. The term stroke covers two types of strokes, both causing damage to the brain. The most common comes from blood clots that block vessels and prevent blood from reaching the brain, thereby causing brain damage. The other type is a cerebral hemorrhage, in which an aneurism bursts or a weak blood vessel leaks, and the pressure from the blood causes damage to areas of the brain. For those who survive a stroke, some of the most common physical effects include:

- Hemiparesis (Weakness on one side of the body)
- Hemiplegia (Paralysis on one side of the body)

- Dysarthria (Slurred speech or difficulty swallowing)

Along side any physical effects, there are many times cognitive and behavioral changes as well [4].

2.1.3 Disease, Accidents and Amputation

Accidents at home, in traffic or at work with trauma to the head (and /or severe damages to the extremities) can lead to physical disabilities as well. Diseases may also cause amputation, or brain damages that can lead to physical disabilities. Whatever the cause – be it Cerebral Palsy, a stroke, or anything else – the possibilities of improving and enjoying ones life with a physical disability are not static, and can potentially be enhanced through music.

3. BRAIN PLASTICITY AND MUSIC

Our brains are capable of continual change via plasticity, which is a fundamental (re)organizational function of the human brain. Throughout our lifespan, the brain responds and changes its functional and structural organization [5] through events like maturation, learning and memory, adopting physical skills, recovery form injury, or coping with loss of sensory input like auditory or visual input, and much more [6]. This amazing function is extremely important throughout life, both when growing up and learning, but also following a brain injury.
Medical knowledge about plasticity is used in many different ways in rehabilitation, following strokes or accidents. Several studies have shown that intensive practice with e.g. constraint-induced therapy (CIT) [7] [8] with an impaired limb, can result in further recovery, even after reaching a plateau with less rapid progress in rehabilitation [7]. A change in the paradigms used within Music Therapy came from research in the mid-1990s focused on the relationship between brain functioning and music, demonstrating the experience-dependent plasticity [9] [10], and suggesting that music stimulates complex, cognitive, affective and sensorimotor processes in the brain [11] [12].

Why is music interesting when talking about plasticity? Music performance is one of the most demanding cognitive challenges that the human brain can endure. Music performance requires a number of advanced and precise skills involving auditory-motor interactions, activating areas in the brain such as the Motor Cortex, Dorsal and Ventral Premotor Cortex, Frontal Cortex, Superior Temporal Gyrus, and the Audio Cortex [13]. This broad exercise of the brain is why musicians are often used as examples of brain plasticity, with clear differences between a musicians and non-musicians brain. G. Schlaug et al. [14] compares the brain and cognitive effects on young children who had instrumental music training with children without any prior training. The research shows that certain transfer effects start to emerge in an early age, and get more and more pronounced as training continues. It comes as no surprise that structural changes appear in the areas linked to musical training, however very interesting structural differences occur outside these areas as well. This is an indication of transfer effects, which may indicate that playing a musical instrument would benefit other areas as well. Such research shows that playing music could be important for general cognitive rehabilitation purposes, as well as pure enjoyment and physical rehabilitation.

4. MUSIC-SUPPORTED THERAPY

The increased interest and research within the field of neuroscience and plasticity has altered the perspectives of traditional music therapy, that usually is connected with topics like well-being, emotional response and relationship building – to a new model called Neurologic Music Therapy [9]. NMT has its focus on rehabilitation following e.g. strokes, and has grown rapidly over the last 20 years. In a series of papers [15][16][17] S. Schneider et al. compares a widely used rehabilitation method to improve motor skill recovery following a stroke, with a music-oriented approach. The method often used in rehabilitation is called CIT, which stand for Constraint-Induced Therapy. CIT is a standardized intensive rehabilitation intervention where the healthy extremity is in constraint several hours a day, thereby forcing the person to increase the use of the impaired extremity. The goal is through a high increase in use and thereby repetitive usage trying to cause plastic reorganization of neural networks in the brain [8].
Schneider et al. suggest a method they call Music-Supported Therapy (MST), which still builds on repetition but at the same time draws upon the additional benefits of active music making. They designed a training program according to the following principles:

- *Repetition:* Repetitive exercising of simple finger and arm movements.
- *Auditory Feedback:* Reinforcement of movement effect due to immediate auditory feedback supporting the precise timing control of movements.
- *Shaping:* Adapting the complexity of the required movements according to the individual progress.
- *Emotion:* Increased motivation of the patients due to the playfulness and emotional impact of making music and acquiring a new skill.

Their results compare conventional (CG), functional (FG) and music-supported therapy (MG) in a variety of tests. The results show MG as a substantial improvement in most test parameters pre- and post-test, when compared to CG and FG. However, their results are not conclusive as single variables need to be identified and further test will show which are significant, but there are clearly some aspect of music creation that yield far better results than conventional CG and FG rehabilitation methods [17].

5. MUSICAL INSTRUMENTS FOR PEOPLE WITH PHYSICAL IMPAIRMENTS

The musical instruments used in S. Schneider et al.'s research are two commercially available products. One is a standard MIDI keyboard, and the other an electric drum set. The position of these devices was altered to fit the disabilities of the individual users in the test, but the devices themselves were not altered or modified in any way.

5.1 Example of Custom Instruments

S. Schneider et al. uses existing products for their research, which can work in certain cases. But it is also possible to create custom musical instruments designed for people with physical disabilities. Historically speaking, there have been a small number of such musical instruments targeting users with physical disabilities. We exclude instruments for those with cognitive disabilities, as it can often be the case that cognitively impaired users still have good enough motor skills to physically engage and play normal musical instrument as intended. Instruments for physically disabled users have come from either researchers or commercial vendors, as described below (in order of publication/release date).

Soundbeam (1989) [18] is a well known and well established commercial product for music creation for people with disabilities. It is also called 'the invisible expanding keyboard in space'. The soundbeam can use up to four beams that each consist of a housing containing an ultrasonic range sensor. The beams are connected to a hub that interprets the signals and extracts note and velocity for each beam and converts to MIDI. MIDI signals are then sent to a DAW or other music software that can playback samples. The beams have a range from 15 cm to 6 meters and can be divided in 64 notes.

EyeMusic (2004) [19] is both a performance and a playback instrument. EyeMusic uses an eyetracker that output the gaze position (x, y) 60 times pr. Second. Max/MSP is used for grabbing the eyetracker data. It operates with eye fixation, that has two parameters, deviation and duration. An obvious target group is people with severe disabilities or spinal injury, who may not able to move their body at all.

Movement-to-music computer technology: a developmental play experience for children with severe physical disabilities (2007) [20]. The MTM system consist of a web camera, screen and speakers connected to a computer. The camera captures the movement of the user. Tiny movements such as raising an eyebrow, to big movements such as waiving the arms are captured alike by the system. The screen shows the user, with colored shapes superimposed around their silhouette. These shapes correspond to a region of physical space surrounding the user, and a note is triggered when part of the body penetrates the boundary of one of the coloured shapes. This gives a visible and auditory feedback to the user, indicating that the shape has been activated. This adaptive approach is highly useful for a broad range of users.

Skoog (2008) [21] is an musical interface that where you can push 5 pads, hit it, squeeze it and twist it. It can play sounds using its own software or hook up to other software using its MIDI capabilities. It can expressively play five pre-defined notes that can be changed using the following software.

Beamz (2009) [22] is a controller consisting of four IR-beams. Each beam can be set to send a MIDI signal, thereby triggering any music software or hardware that supports MIDI. As the Beamz design only catches users interrupting the IR-beams, it is only trigger events that are generated (no velocity), and is also not able to take advantage of e.g. modulation that MIDI offers. However, Beamz is rather inexpensive, and targets schools for beginners to start experimenting with music, or as a tool for therapy and rehabilitation to inspire to movement and the enjoyment of music creation.

Computer Assisted Music Therapy: a Case Study of an Augmented Reality Musical System for Children with Cerebral Rehabilitation (2009) [23] uses an augmented reality system where coloured markers in front of a webcam represent a certain instrument and a particular note of that instrument. A note is played when a hand is in the centre of the marker. The use of the augmented graphics of the system is somewhat unclear from the publication, and the system is tested on a single individual, a child with CP of an unknown age, in a music therapy session. However, is suggested that he system could be used in daily sessions and clinical use.

TouchTone (2010) [24] is design for children with hemiplegic cerebral palsy. The unaffected hand triggers pitches using pressure sensitive pads, and the affected hand is used to shift pitches by invoking a momentary switch. The pressure pads are arranged in two rows of five where one row is a pentatonic scale and the other row can ad a note there has a pitch difference of a 3rd or a 5th of a corresponding pad. There is a LED on each pad to signal if it is active. This can be used as a learning mode, that allow the user to follow the LEDs. It was tested as an individual instrument with 6 children between 8 and 12 years of age, for 15 minutes each, as well as a group instrument with 12 children accompanying a music therapist.

Tongue Music (2010) [25] uses Hall sensors placed on a custom headset which acts as receiver for a magnet affixed to the tip of the tongue. The changing magnetic field is used as input. Moving the tongue creates different magnetic fields, which are interpreted by a microprocessor before being sent to a computer for sound creation. The instrument can play 10 minor and major notes as well as ambient sound, as designed. Tongue Music was demonstrated and 25 couples participated in what seems to be an unstructured test.

EyeGuitar (2010) [26] uses Eye Gaze as a mean of simplified input to play a guitar hero style game for people with disabilities. It is not a true musical instrument, as it can only play the selected song. However, it is a showcase of how to approach eye gaze/tracking for people with disabilities.

MusEEGk: A Brain Computer Musical Interface (2011) [27] creates a BCI using EEG to measure the P300 response. The BCI controls a sequencer, where the user can select notes on a matrix on a screen and position them in the sequencer grid. The sequencer itself has no latency, but current BCI technologies have a high latency. This leads to a limitation that the user at most can select or change 3 notes per minute with an average accuracy of 86%.

Robot-Assisted Guitar Hero for Finger Rehabilitation after Stroke (2012) [28] is a lightweight robot assisting the user in a naturalistic grasping movement of individual fingers. As the title states, a variant of the guitar hero theme was used to test the robot.

Rhyme: Musiking for All (2012) [29]. The RHYME project is a project that investigates the term musicking through Participatory Design and Design for All. The project has made two prototypes called ORFI and WAVE. "ORFI is a set of co-creative tangibles: The ORFI modules, or cushions, communicate wirelessly with each other. They can be freely built, thrown, played in and with as the user like. ORFI responds with changeable graphics, light, and music when the wings of the modules are bent, or the microphone is activated."[29].

Brainfingers (2013) [30] is a hands-free computer control developed by Brain Actuated Technologies Inc. A headband fitted with sensors detects electrical signals from facial muscles, eye movement and brain waves. Brainfingers does not directly target music creation, as it can solve many tasks such as simple clicking, to complex combinations of controls. It is software that converts all the sensor input data into controls termed Brainfingers. This software is useful for a broad range of users, especially people with severe disabilities.

"Musical co-creation"? Exploring health-promoting potentials on the use of musical and interactive tangibles for families with children with disabilities (2013) [31] is an article building upon the RHYME project. The article focuses on actual interaction with ORFI and co-creative tangibles. It has a primary focus on two users, a boy and a girl, and it discusses the theories behind

the project, and how the children with their cognitive and physical disabilities interact with the system. The focus is on how users can benefit, but the article also discusses what might need to be changed in a future context.

The Actuated Guitar: A platform enabling alternative interaction methods (2013) [33], The Actuated Guitar: Implementation and User Test on Children with Hemiplegia (2014) [34]and Exercising the Tibialis Anterior Muscle of Children with Cerebral Palsy for Improved Neuroplasticity Using an Electrical Guitar (2014) [35] is a series of papers describing a project with focus on enabling or re-enabling people to play a real electric guitar. The guitar is a fully functional guitar that can be hooked up to a guitar amplifier. The system uses a linear actuator for strumming the strings, and the neck is operated as usual by forming normal chords. In its current state, it is not able to mute individual strings or skip strings. The idea of modifying existing instruments is to open up the existing musical world for people who are not able to use their strumming hand, either as beginners or people who have played all their life and after a stroke or similar, are not able to play normally any more.

RoboTar (2013) [36] started as a kick-starter project, but was cancelled because of the low interest in the project. The device was finished anyway and is now a product you can by from the inventors' site. RoboTar is a device you strap on the neck of the guitar that can press down notes on all six strings along the first four frets. It is replacing the fretting hand/left arm for people with injuries and or disabilities. The device can be programmed from an app and you can cycle through pre-programmed chords via a foot pedal.

6. CONCLUSTION / DISCUSSION

Performing music may or may not be inspiring for a particular person, no matter if it is during rehabilitation or not. However, it has enough potential benefits to justify that music-focused rehabilitation should be offered to those who would be interested in music-based therapy. That said, some are more into football, biking or running – and the broader the support within rehabilitation, the better. In the long run, it should be whatever motivates the individual to keep them on the path to rehabilitation.

The main criteria of Schneider et al. [15][16][17] was that the patients should have residual function of the affected extremity above a certain threshold, before they could contribute to the research. This makes sense, as the goal was to investigate if MST would improve the dexterity and motor function of an effected extremity, compared to traditional methods.

Using existing musical instruments for people with residual function in one or more extremities is an interesting approach, and opens up for a broad range of possibilities. Taking a drum kit as an example, this could be well suited for people with residual function in both upper and lower extremities, since they need to use both hands and feet when playing a drum kit. Drums could also be a good place to start for exercising coarse motor skills, rhythm, memory and timing. For exercising fine motor skill in the upper extremities (hands and fingers), piano or keyboard may be a good choice, as it gives the same benefits such as motor skills, rhythm, memory and timing.

But what is equally important is motivation and goal-setting [37]. It is well known that for improvement, practice is key. Practice without motivation is difficult and often results in skipping practice, meaning users will not reach their goals. By using (potentially modified) existing musical instruments, however, the benefit of constant inspiration from music on the radio, songs played in TV or on the Internet becomes present.

In addition, existing musical instruments can potentially open up for social activities more easily than entirely new instruments. When using existing musical instruments (modified or not), one can bring their instrument to normal instrument lessons, or even join a band. Socializing is a crucial part of music, and is highly motivational (just as playing in team sports is for some).

But what about people with no residual movement in the effected extremities? What options do they have for exploring the joys of playing a real musical instrument, and gaining some of the same benefits as described above? Looking at the review of instruments designed specifically for people with disabilities, there are not a lot of existing / modified musical instruments. The development of instruments for people with disabilities often follows the trend of technological advances, which of course make sense to explore the new frontier technologically, and see if that can solve what other technologies before could not. But there is a remarkable lack of interest in making existing musical instruments accessible for people with moderate physical disabilities, who are well functioning enough to still have a social life and do self rehabilitation. People who have played music their whole life, but are then hit by a stroke end up from one day to the next e.g., not being able to move one arm. Only three papers in this survey, and one commercial product focus on an existing musical instrument.

If one follows the newest technological solutions, it might be argued that the "Holy Grail" within musical instruments for people with physical disabilities, would be a 100% adaptive instrument. Such an instrument would always fit the user, and give them the degrees of freedom and expression that people without disabilities would have. However, it is our suspicion that after an initial honeymoon with such an instrument, most would lose interest in it. People often learn by imitating other people like their parents, siblings, friends, teachers or coworkers. But an adaptive instrument would give different gestures for a given sound for different users, meaning that it will never be able to be replicated in the same way as another user. This isolates players, making it impossible to learn from each other directly. One of the most exiting and challenging parts of playing a musical instrument is to learn from others playing the same instrument.

7. ACKNOWLEDGMENTS

Funding for this work was provided, in part, by grants from Ludvig og Sara Elsass Fond in Copenhagen, Denmark.

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