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Designing Musically Assisted Rehabilitation Systems

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Abstract

This article reviews the process of designing technology to meet specific needs during rehabilitation-oriented music therapy. Individuals with acquired brain injury have unique needs, many of them involving physical rehabilitation. These needs are evaluated throughout the music therapy processes described and provide the foundational guidelines for new instrument designs. The article suggests that instruments designed with rehabilitation goals in mind may differ from traditional music instruments. Music technologies (musical instrument digital interface [MIDI] instruments and software) developed by the author to facilitate particular interventions during music therapy rehabilitation will be described. An embedded "Midi-Fly" technology that captures quantitative data related to these interventions will be explicated.

Keywords

synomorphic design, somatosonic experiences, somatosonic identification, gestural technology, purposeful exercise

Introduction: Form Follows Function

The foundational principle that form follows function[1] has long been the hallmark of the functionalist approach to architectural and industrial design. The principle summarizes the seemingly obvious idea that the form of an object should be created initially by developing a comprehensive understanding of the function or purpose the object is set to serve. The subsequent structural designs are the result of informed choices that are based on investigations into the direct relations between the mechanics of the design and the functional achievement. When considering the design features of musical instruments and the technologies employed during music therapy practice, questions arise as to the relationship between the form and the function.

Music therapy, as defined by the American Music Therapy Association (AMTA), is the clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship by a credentialed professional who has completed an approved music therapy program.[2] The functional aspects of music therapy according to this definition are "the clinical and evidence-based use of music interventions to accomplish individualized goals."[2(p7)] Older definitions of music therapy provided by the National Association for Music Therapy (NAMT) offer more details about what was thought, at the time written, to be the aim or intended function of music therapy: "the use of music in the accomplishment of therapeutic aims: the restoration, maintenance and improvement of mental and physical health."[3(p11)]

If the evidence-based use of music to restore, maintain, and improve mental and physical functioning is the purpose of music therapy, then it would seem to follow that the form of music therapy, the activities designed, and the instruments employed, would greatly differ from other musical formats designed to entertain, support culture, energize a campaign, express religious dogma, bring personal pleasure, or facilitate sales. If form followed function with regard to the musical instruments used in physical rehabilitation, then music instrument design might reflect the need to exercise specific physical function. If form followed function in relation to the provision of evidence that music and music-making processes are effectively addressing therapeutic objectives, it would seem that some part of our music therapy technology would involve monitoring such effectiveness.

Most musical instruments and technologies utilized in music therapy are not unlike the instruments that performing musicians use. Music therapists have long purchased the instruments of their trade at music stores that offer acoustic and electric guitars, acoustic and electric keyboards, percussion instruments, and even advanced music software and musical instrument digital interface (MIDI) instruments. The music therapist, especially when working with individuals having disability, had to modify these instruments to meet the functions of their practice. Now that expansive MIDI musical

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instruments and gestural technologies (technologies that register movement and convert this movement into music; see note 1) are produced, music therapists are implementing them into practice.[4] As computer-based recording systems[5] and loop creation programs that allow patients to compose music instantly are produced (see note 2), music therapists are using them. Since these new technologies are not designed with specific music therapy functions in mind, music therapists may find that they need to learn more about the hardware and the software of technology in order to modify these instruments to meet clinically determined goals.

The following case examples describe the challenges involved when technology and traditional musical instruments are introduced into rehabilitation music therapy and how modifications were needed to meet the needs of the work. Through a series of modifications to traditional musical instruments and existing technologies, new instruments were developed.

The review of these developments starts with a description of the needs of the patients being served as it is these needs that informed the emerging instrument designs.

Developing Musically Assisted Rehabilitation Systems as Interventions to Clinical Needs

The Presenting Needs of Patients in Rehabilitation

Acquired brain injury can result in problems with physical movement, communications, somatosensory processing, cognitive processing, and emotional functioning. Patients coming to rehabilitation services are limited in their abilities to master their physical environment and are often so impaired that they cannot execute basic activities of daily living (ADLs) such as feeding, grooming, and dressing themselves. Traditional occupational and physical therapies evaluate existing levels of functioning and then create a treatment plan designed to exercise movements so that range of motion, muscle strength, and motor-timing improve and expand.

Motivation toward these rehabilitation exercises is an area of great concern and is often determined by the perceived "purposefulness" of the activity.[6] Sometimes patients perceive the rote exercises on traditional exercise cycles, weighted pulley machines, and step machines, as purposeful, especially during the initial sub-acute treatment when rehabilitation is more likely seen as high priority. At times, patients seem to require "added purpose"[7] to remain motivated in their exercises, especially if the patient is depressed or in long-term treatment and perceives the exercise as one more painful experience to endure.[8]

Adding purpose to rehabilitation exercises has taken many forms, including electronic music making,[9] mini-basketball dunking activities,[10] and playing video game programs. The success of these purposeful exercises is not solely dependent upon their ability to engage patients in exercise but also in the exercise's ability to physically mobilize appropriate movements and provide somatosensory feedback typical to physical and environmental challenges.[11]

Embedding rehabilitation exercises into music-making activities is not new to the field of music therapy and the benefits of such activities have been noted in music therapy and occupational therapy literatures. Thaut[12] notes the benefits of combining musical motor learning to functional movement exercises. The implications of these embedded exercises studies are that rhythmic cues help initiate and support movement, and that these exercises in turn improve physical functioning once muscle strength and motor timing are strengthened. Paul and Ramsey[9] noted similar observations in that joint range and muscle coordination are achieved more easily when purposeful range of motion exercises are combined with electronic music-making activities that provide positive feedback to the participants. Thaut et al[13-15] suggests that rhythmic auditory stimulation improves gait velocity, cadence, and stride length and stride symmetry in patients with stroke.

Case Study

Frank was a 47-year-old veteran living in a 500-bed skilled nursing facility. After sustaining traumatic brain injury during an automobile accident, Frank's motor skills were so impaired that he could not walk, talk, bathe, groom, or feed himself. Involuntary muscle contractions complicated Frank's movements and reduced his range of motion. His fine motor skills allowed him to hold objects but not to manipulate them in any meaningful way. Born and raised in the surrounding community, his mother visited him often and left signs all around his room reminding him to speak (he could, with much effort, produce staccato, coherent utterances) and to put his clothes in the laundry basket. Despite his noticeable impairments, Frank was cognitively alert and capable of complex communications. When asked to complete a task, he still had the discipline of a military man.

As Frank entered individual music therapy, his occupational therapist recommended that I elevate the musical instruments so as to exercise his range of motion and to experiment with different sized handheld objects in order to facilitate more fine motor movements. For months I experimented with various instruments (drums, xylophones, shakers, and different sized drumsticks) and instrument positioning in an effort to determine his current level of functioning. Once established, a profile of baseline physical capabilities could be used to create an adaptive musical instrument that he could manage.

The Challenge

Frank's range of motion and muscle strength were certainly sufficient to produce movements needed to push or strike a physical object, but his fine motor impairments prevented him from being able to strike a drumhead and then retrieve the tip of the drumstick from the drumhead in order to allow the drumhead to resonate. The strike and retrieve impairment prevented sound production on acoustically designed instruments as the sustained force on the drumhead or metal bar muted the sound. Using a piano, even a light electronic piano, would make sound production easy, but these instruments would complicate the possibility of intricate instrument positioning. Gestural technology that converted movements in space into sampled and synthesized sounds was available, but these instruments would entail the sacrifice of key somatosensory components related to rehabilitation: vestibular, kinesthetic, and cutaneous feedback. Frank's fine motor digit control was severely impaired, but he was able to grasp, with a fixed grip, a drumstick.

Designs that facilitate particular behaviors, or movements in this case, are referred to as synomorphic designs. The challenge to construct a synomorphically appropriate musical instrument that could exercise range of motion, gross and fine motor functions, depended upon a design that included 2 features. First, instant and easy adjustments to instrument height and angle; and second, trigger sensitivity suitable to both the "thud-like" strikes on the drumhead (strike without retrieval) and light grazing brush strokes that were also a part of Frank's music-motor repertoire. Due to Frank's auditory/sensory impairment, it was suspected that full, complex sounds would engage and stimulate him to consistent participation.

Technology Solution

After months of experimenting, a technology-based solution was found. Piezoelectric sensors (see note 3) were embedded onto the back surface of paddle drums that were mounted to heavy duty, height and angle adjustable, cymbal stands. Velocity-sensitive piezoelectric signals were sent to a MIDI converter that forwarded digital musical information to a Korg M1 sound source. The Korg sound source provided hundreds of deep rich sounds that were sent into a 4-speaker, surround sound audio system. This MIDI range of motion system accepted Frank's existing music motor movements and converted them into sounds that were dynamically related to the strike, touch, and grazing force initiated. Frank now had access to purposeful, sound-making experiences while simultaneously executing rehabilitation exercises. The project seemed like a success but raised many questions.

Was the synomorphic design of the range of motion system creating a situation where the experiences related to "exercise" overshadowed those of "music making" and thus diminishing the positive effects of a purposeful, enjoyable activity? Should fine motor rehabilitation exercises be embedded simultaneous to gross motor and range of motion exercises? Given Frank's limited fine motor abilities, would a textured MIDI surface that responded to hand and finger movements address more pressing physical challenges? Would a MIDI handheld object provide more personal expressive options than the range of motion system? The answer to these questions would come to influence many future design decisions.

Research and the Range of Motion System: Synopsis of Control Study

In 1997, a senior occupational therapist, Stanley Paul, and myself decided to conduct a study of music-making activities in occupational therapy. The range of motion system was employed in the study to support rehabilitation interventions.

Participants were selected from the 300-bed skilled nursing facility where both researchers worked. All of the participants had been discharged from occupational and physical therapy and met the criteria of the study that was to test the effects of music-making activity on shoulder flexion and elbow extension: range of motion. A pretest—posttest control group design was used for the study. The control group received recreation therapy where participants were encouraged to move and extend their upper body extremities. The experimental group engaged in music-making sessions with the 2 therapists: the music therapist and the occupational therapist.

Throughout the experimental sessions, the occupational therapist would adjust the range of motion so as to ensure proper rehabilitation exercise movements. The music therapist would encourage, conduct, and engage the participants in dynamic, interactive, musical improvisations. Driving rhythms and unexpected dynamic changes were employed frequently in order to ensure focus, engagement, and enjoyment.

Independent and paired t tests were used to analyze shoulder flexion and elbow extension results from the experimental and control groups. Results from the study showed significant improvement in degrees of shoulder flexion and elbow extension between pre- and posttests for individuals in the experimental group, but there were also significant increases in shoulder flexion with less of an increase for elbow extension in the control group. Several factors (small sample size and possible external range of motion opportunities during other recreation therapy sessions during the test period) prompted the researchers to recommend further research.

The result, although encouraging, awakened the researchers to the need for additional technology assistance. There is "a need to include a kinematic analysis to measure the number of repetitions, movement time, reactivation time, frequency of discontinuities (rest period) and accuracy through spatial motion analysis and video recording."[9(p237)] The researchers never followed up these specific recommendations, but the need for more refined measurement tools did prompt other developments.

Midi-Fly: Covert Rehabilitation Data Collection Program

Cake Walk was one of the earliest sequencing programs available during the 1980s and was produced by a company named Twelve Tone Systems, Inc. Computer sequencers in the 1980s and consumer models in the 1990s recorded exclusively digital information: that is without audio information. Each musical event was recorded along a standard Society of Motion Picture and Television Engineers (SMPTE) time code so that each note could be tracked according to the time of its initiation. MIDI musical events related to note initiation, duration, velocity, and controlled sound modulations were recorded. Velocity of note initiation was calibrated according to a scale with a range from 0 to 127. This MIDI event data could easily be used to register muscle strength, as noted by the velocity data. The range of motion could be tracked by associating the note on/off data

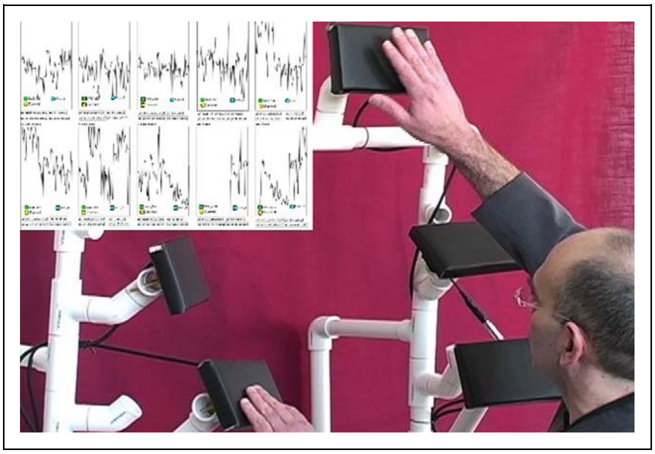

Figure 1. Carlos Cuellar with the R.O.M.M. 1 and Midi-Fly data read-out screen. R.O.M.M. indicates Range of Motion Machine.

with instruments arranged at specified elevations. Note on/off data could also be used to track participation. Motor timing could be quantified by comparing the notes played by the patient to the stylistic downbeat of the music or any foundational rhythmic element of choice.

With an ever-increasing focus on the importance of quantitative research in music therapy,[16] these options seemed very appealing. The fact that all of this quantitative data could be collected seamless of the music-making process made it especially appealing. Like an ethnographic fly on the wall that watched and recorded without interfering in the process, the "Midi-Fly" system seemed, at first, a perfect solution to the ever-increasing need for quantitative data.

Unfortunately, extracting the quantitative information from the sequencing program was a demanding process involving the manual extraction of each piece of data and then registering this data onto an independent statistical recording format. This process was extremely time-consuming and difficult to manage, so it was not practical to implement. Improving the Midi-Fly was beyond my technology capabilities.

In 2008, I met music engineer and composer-turned-music therapist Carlos Cuellar. After listening to my difficulties with the Midi-Fly System, Carlos, an experienced music technologist, expressed an interest in developing a user-friendly version. Six months later, the Midi-Fly Software Program was ready. The Midi-Fly program was designed to capture precise measurements of many movement efforts exerted during the music-making process: muscle strength, motor timing, duration, movement accuracy, and level of participation. This tool was constructed using graphical programming software and human musical interface technology including MIDI and open sound control (OSC) protocols. The Midi-Fly creates data streams that can provide numeric charts, graphs, and quantitative text that can be utilized in research and client assessment (see Figure 1). The Midi-Fly is made of sub-patches and abstractions (programming components of Pure Date open software) and is constantly being updated to accommodate different rehabilitation goals and objectives.

When the Midi-Fly software was connected to the latest version of the range of motion system, the Range of Motion Machine (ROMM 1) was complete.

Functional Implications of Musically Assisted Rehabilitation Systems With Midi-Fly Software Programs

The Interactive Musically Assisted Rehabilitation (I-MARS) project commenced in 2010 following collaboration with Carlos Cuellar. The mission of the project is to create musically assisted rehabilitation instruments for a wide variety of rehabilitation needs. The project involves meeting with practicing music therapists, some who are involved in pediatric occupational therapy/physical therapy projects and some working with neurologically impaired adults. Information about specific physical, sonic, and technological features needed is collected and then these ideas are taken into development. Many unique and wonderful instruments have been created and many are being explored and developed: ROMM 1 (vertical range of motion machine), ROMM 2 (horizontal, side-to-side range of motion machine), Midi-Cycle, Midi Hand, MIDI Sound Pallet, and MIDI-Skin. In the process of designing music rehabilitation instruments and computer programs, Music in rehabilitation theories have crystallized and certain design principles have emerged:

1. Synomorphic design entails more than just providing gross motor movements, it entails intricate designs that reflect fine-musical motor needs: hyperexpressive sound initiation components.
2. Certain instrument design features are essential to support somatosonic experiences:
   a. *Immediacy of sound*: Sounds and instrument initiation designs that eliminate latency of sound and provide instant attack features.
   b. *Sound modification options*: Options to change sounds and expressive sound features like pitch bend, filter modulations, vibrato, and effects.
   c. *Somatosensory connection*: Ever-present tactile connection with the immediate sounds produced.
3. Positive, interactive, interpersonal music-making experiences and embedded rehabilitation exercises share equal priority in music therapy rehabilitation. The design of every instrument shall reflect this principle.
4. Rehabilitation music making entails the provision for somatosonic experiences that result in somatosonic identification of the sounds produced.
   a. *Somatosonic experiences* can be explained as the integrated somatosensory, auditory sensory, and kinesthetic experiences that occur when one's physical movements are recognized or sensed as the origins of sounds being produced.
   b. *Somatosonic identification* is the evaluation of a somatosonic experience that results in the personal ownership of the sounds made and a sense of the many personal decisions made in order to produce that particular sound.

Conclusion

Traditional musical instruments may not provide the rehabilitation music therapists access to features that are needed to meet their therapeutic goals. This is especially evident when those goals are best met by specifically designed exercises. Pre-programmed music software may not provide the quantitative data needed by music therapists who need data to support observed progress or who are conducting research. As increasing components of technology are employed in the practice of music therapy, music therapists may find that they will need to extend their options by either modifying the existing instruments or creating their own. Options such as these may force the rehabilitation music therapist to expand his or her professional knowledge base to include knowledge of MIDI programming features; and until specific MIDI music therapy instruments are available to the rehabilitation music therapists, they may find that they will need to involve themselves in MIDI-instrument hardware modifications so as to meet the physical capabilities of the patients they serve.

Notes

1. Gestural technology. Gestural Music Technology refers to any system that captures and converts external movements into sound. Gestural technologies require no physical contact with an object, string, piano key, press pad, and so on; although there will be some kinesthetic feedback involved in the process of making music, there would be no tactile or fine-motor somatosensory experiences connected to the music making.
2. Garage Band is a software application that allows users to create music by selecting pre-programmed music sections and pasting them together to form complete arrangements. It is developed by Apple, Inc. (Cupertino, CA) as a part of the iLife software package.
3. Piezoelectric triggers: pressure-sensitive devices that utilize the charge released from quartz crystals when pressure is applied.

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Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: It is my desire that music therapists seek new ways to implement technology into their music therapy practice. As I publish my ideas about these concerns, others may contact me and want consultation services. The purpose of this article is not to elicit consultation services but to provide information and options as to how one might use of technology in music therapy.

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Bio

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