The association between electronic music technology and people with disabilities has been long and fruitful, and today opens up the prospect for lifelong learning. The electric piano was first developed to provide an instrument that could sit on a hospital tray, for American flyers recuperating from World War II injuries (Adlers, 1996). With the progression of music technology, other applications of instruments for people with disabilities followed. For example the Omnichord, which is like an electronic auto-harp without strings, can be used in music therapy. Its buttons to control chords and touch-sensitive Strumplate, which produces the effect of playing strings, make for ease of use by persons with disabilities (Actron Qchord Network, 2003)).

After the Musical Instrument Digital Interface (MIDI) standard was accepted in 1982, new possibilities for both common instruments and customized applications quickly emerged. Only a brief overview is possible here. Among generally available instruments, a number of features make portable MIDI electronic music keyboards particularly accessible. The keys are easy to press and can be set at a constant volume. Buttons require only a feather-light touch. Chords can be played using one or two fingers. The same option allows control of all of the rhythm accompaniments. The keyboard can also be set up to play a variety of drum sounds.

Other common options for people with disabilities include MIDI electronic drums and the Suzuki Q-chord, which is essentially a MIDI version of the Omnichord but shaped like a guitar (Actron Qchord Network, 2003). Specialized controllers are MIDI-compatible devices typically used together with keyboards or sound modules. They allow additional ways of accessing music. Switch controllers allow the user to
play music using multiple switches in different ways. Any standard ability switches (e.g. for the hand, head, or using sip-and-puff) may be employed. An example is MidiMate, which has been developed at Bloorview MacMillan Children's Centre for people with disabilities (Knox, 2003). It facilitates playing of song melodies with chords, control of chord progressions and auto-accompaniments, individual tones and other features.

In general, computer software that represents music graphically is particularly useful; it does not require the understanding of standard music notation or of the piano-roll interface used in software sequencers. Alternative access devices replacing the standard computer keyboard or mouse also work well with standard music software that has simple graphical user interfaces.

Music technology applications at Bloorview MacMillan Children's Centre

Bloorview MacMillan Children’s Centre in Toronto serves young people with disabilities and special health or rehabilitation needs, as well as their families, through unique programs and partnerships in research, education and advocacy. It has long-standing traditions of original work in both music therapy and rehabilitation engineering.

Since 1990 our research and development projects involving music technology have focused on both clinical rehabilitation applications and on accessibility to music participation. We have carried out four major programs of research and development: (1) a computer-based music program, ListenUp! for attention remediation in adolescents with acquired brain injuries (Knox & Jutai, 1996; Knox, Yokota-Adachi, Kershner, & Jutai, 2003; Author, 2003); (2) MidiMate, the above-mentioned switch device for access to portable electronic music keyboards, with research on psycho-social benefits for groups of adolescents with cerebral palsy (Greenidge, 2000); (3) development and usability of video capture music software, and related musical skill acquisition; (4) at Lyndhurst Spinal Cord Centre, an electronic music system using adapted hand therapy devices for adults with quadriplegia developed by engineer Tom Nantais (Nantais, Lee, Davies, & Knox, 1993).
In music therapy, we have used music technology in improvisation and song-writing sessions for adolescents with acquired brain injuries. At the Bloorview MacMillan School we have regular music technology classes for children 4-7 with various physical disabilities. Our new Adapted Music Service provides related consultation to other schools, organizations, and families; recently we have set up Sir William Osler Secondary School and Sunny View Elementary School in Toronto, and Five Counties Children's Centre in Peterborough with the MidiMate system. We have had community programs led by music therapists, including an after-school music technology group and a new after-school movement to music group, and also a multimedia recreation program.

**Background**

1. Sensor-based music technology and persons with disabilities

Sensor controllers use infrared or ultrasonic beams, whose distance from an object is converted into MIDI information and used to produce sound through an electronic keyboard or module. Physical gestures and movements are translated into music using this "movement-to-music" technology. Examples observed by the authors in use by persons with disabilities include the infrared controller Lightning (Buchla and Associates, 2002), and the ultrasonic controllers Soundbeam (The Soundbeam Project, 2003; Ellis, 1995) and MidiCreator (Kirk et al., 1994). The Soundbeam along with the video system discussed below were originally developed for dancers to allow them direct control of sound.

We have extensive experience with Soundbeam 1. Since we purchased it in the mid-1990's it has since been superseded by Soundbeam 2®, which has a host of added features (The Soundbeam Project, 2003). The beam can be set at anywhere from 25 centimetres to six metres in length. The instrument is programmed in 10 preset modes, each of which divides the beam into a succession of scale tones. The tones can be played singly, sustained into built up sonorities, or re-triggered continuously. The musical results devolve from the construction. With any
sensor-based digital musical instrument, it is hard to translate analog physical motion into digital music because of the amount of precision required. In addition, with the infrared or ultrasonic MIDI controllers there is no visual interface to guide the user. So without a visual interface it is not possible to play melodies or chords unless they are available as pre-programmed sequences or harmonies, as are now available in Soundbeam 2. Soundbeam 1 is useful for isolated tones or sounds, tone clusters, or series of tones such as that produced by sweeping over the strings of a harp.

We have found the Soundbeam to be especially effective in reading, story-telling and drama settings. Through multi-timbral MIDI, various moods can be created, such as a harmonious mood using a pentatonic scale with harp, flute, and bird sounds, or a mysterious mood using the whole-tone scale with vibraphone and ocean waves.

We have also used it with groups for exploratory movement, body awareness, and learning of musical parameters of pitch, dynamics, and timbre. A great virtue of the instrument is the length of its adjustable uni-directional beam. Groups of students can sit on each side of the beam and enter in and out, a wheelchair can roll through it, or it can be set at a very short length to sense finger motions. Others have used it for therapeutic purposes; a pilot study at our centre noted a tendency toward finer motor control as clients with cerebral palsy worked with it over several sessions (Woo, 1997).

A video camera can be used to track gestures or images that are then translated into sound and music using a customized computer program. The advantage of video is a multi-dimensional image that is much richer in information than a uni-directional beam. One such system, which we have observed used by people with disabilities, is the Very Nervous System developed since the 1980's by Toronto installation artist David Rokeby (Rokeby, 2003). Originally combining software and hardware, it is now available in a software version, softVNS2, which runs in Max 4. It is an object-oriented program that employs sophisticated algorithms to produce interesting and often surprising musical responses to physical gestures. It has been used successfully with adults at the Wascana Rehabilitation Centre in Regina and at the Victoria Conservatory of
Music. Another example of video-based musical gesture recognition is the Toronto-based Vivid Group's GX system, which has a drumming software module that presents the drum kit in an attractive visual interface with feedback (Vivid Group, 2003).

2. Movement-to-Music Project (MTM); Virtual Music Instrument (VMI)

The options for musical access and education for children with physical disabilities are still limited. As mentioned, there have been many advances in music technology in past years. However, the equipment is expensive, knowledge is required, switch technology requires physical contact and strength to manipulate, and the musical product may have limited experiential qualities when considering the user’s musical options such as melody and dynamics. We determined the need for a system designed for children

The current Virtual Musical Instrument system has been in development since 2001 and is being evaluated on two levels: system design and development and usability (Schwellnus et al., 2002). Our interdisciplinary team includes rehabilitation engineers, occupational therapists, a child life specialist, a composer/music theorist, a music therapist, and a psychologist, as well as a number of undergraduate and graduate university students. During stage 1, the team used pre-existing video capture technology, while the music played was standard MIDI files. In stage 2, the object-oriented computer program Building Blocks was the basis for development (AuReality, 2003). With Building Blocks plus new customized video capture software, a web camera that could capture the user’s movement and translate them into musical events such as arpeggiated sequences and drum beat patterns. Two instrument sounds were to be selected by the user from a list of MIDI instruments, and each sound assigned to 50% of the screen on either the horizontal or vertical axis. Changes of pitch could be made with movement away from the centre of the screen.

Figure 1  
Figure 2
Figures 1 and 2. Children using Virtual Musical Instrument system.

Although the systems used in stages 1 and 2 allowed a child musical access, the team felt a need to specify what would be required to qualify the movement to music system as a musical instrument suitable for children. The following items were identified: quality sound that could be related to acoustical instruments, clarity in terms of cause-and-effect, and the ability to manipulate tempo and dynamics.

**Goals and Development**

For children with physical disabilities, success-oriented movement can be challenging. Stage one of the technology provided the children with a system that responded to their unique movements and that was non-invasive and non-contact. As long as it was within the camera’s range, any movement was translated into a musical sound. However, the children had little control over the sound with limited ability to designate the camera’s area of capture for their unique movement patterns. This proved to be tricky for children with cerebral palsy. Often hand over hand support was required to stabilize one arm in order to clearly distinguish the music produced with movement of the other arm with only the child’s image on the computer screen or television as visual feedback. These challenges led the team to design the first version of the movement to music system (stage three). The development of defined areas of camera capture permitted the user to draw circles or squares with the computer mouse, and to fill in these areas with a colour or picture of the chosen instrument. These shapes could be moved around the image of the child, allowing maximization of each child’s movements rather than the child having to adapt to the demands of a pre-set system. This also permitted the possibility of musical cause-and-effect recognition. The child now knew that a defined area (learned through colour/picture recognition or spatial relations) produced a specific tone. It was also in stage three that we began to experiment with melodic access using a colour system to distinguish each tone of the C major scale. The success of melodic acquisition through rote practice or coloured cue cards as prompts led us to believe that the development of a Virtual Musical Instrument (stage four), and the provision of music lessons was a logical future direction.
Normalized positive experiences gained from involvement in music go a long way to address issues of self-esteem and self-identity. In order to address this need, it was determined that the children involved in stage four would be involved in Virtual Musical Instrument lessons. This experience was to approximate instrumental lessons available to most children including technique exercises, listening, and learning the melody of at least one song from a pre-determined list. Each child was expected to practice at home and was encouraged to develop performance skills such as song announcement, bowing to the audience, and visualization of success at the end of each lesson. At the end of the lesson period, each child was encouraged to perform for his or her family and team members.

As in all music education experiences, both stages three and four provided the opportunity to address cognitive goals such as attention span, memory, and sequencing. In stage three, we encouraged children to participate in cued activities such as “If You’re Happy and You Know It,” and experimented with teaching five tone songs aided by a colour coding system (e.g. the note C would always appear as a blue circle). Memory and sequencing were challenged in a more meaningful way in stage four. Formal music lessons approximately 30 minutes in length were introduced. Children were required to review the lesson from the previous week, learn new material committed to memory from listening assignments, and then check their retention of the day’s lesson through performance practice. Sequencing was approached by rote and spot-practicing.

Visual attention was addressed in the transition between stages one and two with the introduction of the interface with customizable size, colour, shape, and location of icons on a projected screen, providing a multi-sensory experience. An improved set of instrument sounds and more pitch options were also included. This transition also provided the opportunity to include sensory goals such as auditory discrimination and hand-eye coordination through the correlation of musical tones with visual cues of designated musical areas.

**Methods**
1. Participants

In stage one, we used pre-existing technology with a group of able-bodied children. In stage two, we worked with a group of 5- to 6-year old children with physical challenges attending the Bloorview MacMillan School. There were 7 children aged 2.5 to 7 with mixed diagnosis (cerebral palsy or spinal muscular atrophy) participating in stage three of the research study. For stage four, we invited older school-aged children with physical challenges to enrol in Virtual Musical Instrument lessons. These children were diagnosed with either spinal muscular atrophy (SMA) or cerebral palsy. Informed consent was obtained from all participants and their guardians.

Spinal muscular atrophy is a disease of the anterior horn cells of the spinal cord affecting the proximal voluntary muscles, or those muscles closest to the trunk of the body. There are four distinct types of SMA: Type I Acute (severe) or Werdnig-Hoffman Disease, Type II (Chronic), Type III (Mild) or Juvenile Spinal Muscular Atrophy, and Type IV (Adult Onset) (Families of S.M.A., 2003). Types I to III are progressive, meaning that the children will lose functionality in their muscles over time. The children included in this stage of the study were of Type III. The children’s physical abilities varied from mild challenges with fine motor skills (individual digit movement) to limited control of arm movement from the trunk.

Cerebral palsy differs from SMA in that this diagnosis is a non-progressive group of disorders that affect body movement and co-ordination (Ontario Federation for Cerebral Palsy, 2003). It is caused by brain damage during the brain’s development (pre-natal to approximately the age of 3). Basically, it is the interference of messages from the brain to the body and vice versa. Symptoms can include muscle tightness or spasms, involuntary movement, challenges with gross and/or fine motor skills, and difficulty with perception and sensation. The participants in our study generally had difficulty with spastic and/or uncontrolled movements, as well as targeting and proprioception.
Due to challenges in access, children with physical challenges such as SMA and cerebral palsy encounter decreased opportunities for play. As a result, children may not maximize their potential physical activity and show poor coordination, limited range of motion, and lack of motivation to develop or maintain muscle tone. This may also lead to social isolation, poor self-image, and a lack of esteem-building social experiences such as music lessons and performance. Even if children are determined and supported in their training as musicians, access to conventional musical instruments is limited by their unique physical challenges and varying levels of endurance.

This system has the potential to address goals in the physical, cognitive, communication, sensory, and social domains. When considering these goals in the context of music recreation, education, and performance, the team was able to make significant modifications to the system to meet potential goal areas and address the issue of usability.

2. Application in Music Therapy

Music therapy is the clinical use of music and its elements by an accredited music therapist to restore, maintain, or improve mental, physical, emotional, and spiritual health. Music’s structural, non-verbal, and stimulating nature is used to build a therapeutic relationship. Music therapy practice includes observation, assessment, the establishment of goals, and intermittent evaluation. A variety of clinical techniques and musical styles can be used, depending on the needs of the client.

An important aspect of music therapy is the client’s opportunity to be an active participant in the music presented. The therapist cannot force a client to make positive changes. He or she can only create an environment that facilitates or encourages goal directed change within. An example would be the expressive communication of feelings through music improvisation. For children with physical disabilities, traditional instruments used in music therapy practice can be a source of frustration. Often, the instruments are difficult to hold or manipulate. The sound produced may be somewhat limited by their range of motion or strength of grasp and may not capture the child’s musical expression. The
human range of feelings is broad, so the more emotive and flexible an instrument is to each child’s movement, the more likely it will meet or speak their feelings.

Many music therapists have had to spend considerable time adapting traditional musical instruments to meet the needs of clients with physical challenges. This may include the use of tape, velcro, string, wire, stands, etc. It often results in an instrument that is too heavy to manipulate, that may have an unreliable or distorted sound, or has an element of discomfort for the client.

The virtual instrument has provided an opportunity to customize the instrument to the strengths or abilities of the children in a small or large range of movements. Another important feature of the VMI is the non-invasive, non-encumbering nature of the system and the motivation it provides each child to interact in a playful environment. This is further enhanced in structured tasks presented to the children dependent on their developmental ages and musical interests.

Many different musical structures were employed through stages two to four to musically frame and enhance the children’s experiences and address the issue of usability. To reinforce their experience of cause-and-effect in stage two, the music therapist engaged 5- to 6-year old children in cued task songs such as “If You’re Happy and You Know It” and the “Band on the Bus.” In addition to cued tasks, a pentatonic scale was designed for each child in stage three. The children were encouraged to improvise freely or play a duet with the music therapist’s voice. Another option for the school-aged children in this stage was to learn to play a favourite song with no more than 5 to 6 tones using coloured circles coordinated with specific tones, with cue cards as prompts. It was the success of this task that led the team to believe that formal virtual musical instrument lessons were possible for stage four. In all cases, social reinforcement was used to address issues of self-esteem and reinforce success made.

3. Suzuki Method
The Suzuki method of music education was employed as a loose structure and teaching tool for stage 4 of the study (Suzuki, 1995). This method was utilized because it permits the student to learn music on an auditory basis, emphasizes that practice and performance are to be done from memory, uses familiar melodies (and if the melody is not familiar, it becomes so with listening homework), involves other family members, and is appropriate for those children with visual impairments or at a pre-reading level.

Each child was supplied with a compact disk of book one (piano version), a copy of the software and a web camera for their home computer, and a floppy disk containing the C major scale set at their first lesson. Each note name of the scale corresponded with a coloured circle (for example C equals blue, D equals red, E equals yellow, etc.) and was placed within the child’s best area of movement by the instructor. If possible, the coloured circles were to be placed in an ascending order according to their pitch from low to high. For those children with limited physical access or cognitive issues, only the colours/notes required for that particular lesson were included on the screen.

Because the system lends itself to the playing of melodies, a closer look at melodic construction is useful (Figure 1). The two songs "Twinkle, Twinkle Little Star," and "The Honeybee" (Bohemian folk song) are shown as illustrations. The first is a classic "gap-fill" melody with an opening reaching motion followed by a gradual descent corresponding to the concept of tonal gravity. The second also has an overall descending line with circling motions around structural tones. Other characteristics include: closed ABA form, use of a motive, sequence, and limitation to two rhythmic values. The clear form, rhythmic simplicity, and familiarity (in the first case) make the melodies suitable for beginners. In addition, the Virtual Musical Instrument offers the unique possibility of aligning melodic motion and gestural motion in a visual, aural, and kinesthetic context. Analyzing the frequency of melodic motion types (Chart 1) is a key aspect that can be used to determine level of difficulty. Melodies with repeated and conjunct motion and few changes of direction (e.g. "Twinkle, Twinkle Little Star") will be easier to learn than those with disjunct motion and frequent changes of direction (e.g. "The Honeybee")
Twinkle, Twinkle Little Star

Form:

A       B       A

Characteristics:

Classic gap-fill -- reaching motion followed by gradual descent

5-Line (Schenker)

Tonal gravity, closure of form, uses motive, sequence, 2 rhythmic values only

The Honeybee (Bohemian Folk Song)

Form:
Characteristics

5-Line (Schenker) with prolongations in circling motions around structural tones,

Tonal gravity, closure of form, uses motive, sequence, 2 rhythmic values only

Figure 1. Description of Songs in Virtual Musical Instrument Project. Scores to be added
4. Ongoing development of VMI

As our system design and usability study progresses, we continue to study ways of making the Virtual Musical Instrument accepted and utilized as a conventional instrument. As we begin stage 5 of the study, several modifications have been made to improve the interface, system speed, image capture sensitivity, computer compatibility, velocity, and ease of use. It is also our intention to expand the population base accessing this system. This instrument will be introduced to adult music groups with similar diagnoses in the near future.
The future of the virtual musical instrument and movement to music technology is strong. Currently, the system is being further developed in a new direction in a study that is examining the acquisition of skills for computer-based leisure activities for teens living with the effects of traumatic brain injury through movement recognition and virtual environments. Also, a program with the Virtual Musical Instrument is being offered as a service for children in the surrounding community. This has expanded in 2004 to music therapy services, which will utilize the virtual musical instrument as a therapeutic tool to address many different goal areas such as socialization in turn taking and sharing tasks, or communication/self expression in clinical improvisation.

We believe the acquisition of musical knowledge and skills on the virtual musical instrument can provide opportunities for independent creative expression, musical mastery from solo performance, and the future potential to interact with other children in musical social situations such as band practice or choir rehearsal. This may lead to an enriching, lifelong learning relationship with music for every child in our society.

References


Woo, A. (1997). Applications of Soundbeam music technology with children with disabilities. 4th year research selective paper, Dept. of Occupational Therapy, Faculty of Medicine, University of Toronto.