Abstract

We gave 32 people with cerebral palsy the opportunity to use a motion tracking system to convert their movements into musical sounds. Due to their physical limitations, people with Cerebral Palsy have traditionally had fewer opportunities to make music or dance. Motion tracking can palliate this inequality, since it permits any movement to be mapped to music and sound. We used two sensor systems: a video-camera based system and electrode-based physical touch system. The former is based on human motion and the latter requires physical contact between therapist and subject to control sound. By correlating each subject's physical handicap with specific movement-to-sound mappings, we gained insight into how motion tracking can be used as an artistic tool for people with cerebral palsy.

1 Introduction

Cerebral palsy is a non-progressive motor condition that limits a person's ability to control movement. CP describes a “group of disorders of the development of movement and posture, causing activity limitations, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behavior, and/or by a seizure disorder” (Bax et al. 2005). There are approximately 20 million people in the world with cerebral palsy, or one person for every 350. The incidence of cerebral palsy, which is about 2.4 cases for every 1000 births, is not decreasing and may in fact be rising.

Most people think of motion tracking as a tool used by animators and media artists to generate animated characters with life-like movements. This technology, which is also referred to as motion capture, involves complex and expensive hardware and software. Motion capture systems involve multiple video cameras, infrared sensors, body-worn markers and dedicated proprietary computer systems. The movement data is usually stored on hard drives and retrieved later for rendering and processing. Thus, it is rarely used in real time applications.

Another, less well-known use of a similar technology with cheaper devices is in live interactive performances of dance and music in which dancers or musicians use their movements on stage to generate and control sounds, music or other media in real time. Although simpler than motion capture, such systems allow even very small movements -- such as finger or eye movements -- to be used in artistic settings. Thus, although, the quantity of data is relatively small, it is still sufficient to permit efficient mapping of physical gesture to media and as a result can be used to transform, and, more importantly for our purposes, to make the gestures relevant for expressive purposes.

The project we present here was proposed and sponsored by FUNDACIÓN MÚSICA ABIERTA (Spain) and took place between March 29-31, 2010. 32 people with cerebral palsy were involved in this workshop. Most could not walk unassisted, many could not speak or had highly impaired speech and some could only control head and eye movement with proficiency. (Video in http://www.palindrome.de/cp)

31 of the 32 subjects in our study were children with ages ranging from 5 to 13. We also worked with one 40-year-old man. We worked with each separately in sessions of 15-30 minutes and gave each the opportunity to control music and sounds with their movements.
2 Purpose

The primary goal of this study, and of our continued research, is not to develop tools for normal daily tasks such as the communication, but rather to offer artistic expression through movement and music.

Despite their generally normal intelligence and creativity, people with CP have been largely limited from participation in the performing arts. In other words, they are sometimes denied the possibility to express themselves artistically in this way. There are several reasons to explain this limitation:

- most of the tools available for CP patients are focused on communication or physical assistance.
- the tools for making music and dancing have not been developed, modified or implemented in ways which suit the needs of people with CP.
- the tools that are available are too expensive to be widely available.
- therapists and support persons are not trained in the use of such tools.

It is of great importance that people who cannot speak or walk have the opportunity to express him/herself through art. In this project we worked with 32 people with CP from Centro Obregón de Parálisis Cerebral, in Valladolid, (Spain).

We employed new technology to allow even very limited movements to create sound and music. This occurs not simply in the sense that small movements can be amplified, but more generally in the sense that attaching or paralleling sounds to movement has the effect of making those movements relevant and viable as a means of expression.

According to certain authors, when we listen to music we make use of more concrete and bodily aids to understand it (Marconi, 2001; Saslaw, 1996; Zbikowski, 1997; Feld, 1981; Brower, 2000; Echard, 1999, 2006; Cox, 1999, 2001; Martínez, 2004 and Spitzer, 2004, Peñalba, 2005, 2006, 2008). We understand music in terms of bodily experience: dissonances as tension, resolution as release of muscles, pitch as located in up-down space, ritonello as a cycle, melody as a path leading to a goal, etc.

In an attempt to find intuitive and effective mappings of gesture to sound we make use of these associations. By using our knowledge of music and dance cognition, and by correlating the two with little or no noticeable latency, we are able to elaborate such associations.

Our purposes can be summarized as follows:

- to find new ways to offer music and, in a sense, dance, to people who have traditionally had limited access to it (because of CP).
- to extract conclusions about which combinations of movement, sound parameters and causal relationships (see 4.6 Mapping) are most engaging for the subjects by analyzing video recordings.
- to develop a practicable tool, or set of tools, and methods of working with them which can be made available to persons with CP and other disabilities, their therapists and support personnel. "Practicable" means: inexpensive, quick and easy for therapists and support personnel to learn to use and capable of supporting true (rich) artistic expression for persons with CP and other disabilities. This development includes improvements in hardware, in software, developing a library of patches as well as the music and sounds samples to go with them and systematizing a method of working.
- finally, we are interested in genuine artistic issues in this work. Most people think of art in terms of either therapy, hobby or professional practice. However, there are a number of professional handicapped performing groups with international reputations. That despite, or indeed because of their disability, have unique qualities of expression which can be of real value to an audience.

3. Choreography and music

The quality of the music plays an enormous role in interactive environments. The quality of the music used can, for example, completely alter our sense of what the technology is bringing to the work. We tend to say we like or dislike the technology used according to how much we like the music.

This is, of course, true of movement as well. When an interesting movement gesture results in an interesting sound, we have a strong formula for interaction. The results are stimulating and we are likely to want to repeat the gesture again.

In the performing art world of the 1960's and 70's a movement arose which was championed by John...
Cage and Merce Cunningham. “It held that every sound can be music and every human movement can be dance” Copeland (2003). This simple premise revolutionized music and dance-making and has to this day important implications for interactive music and dance.

Computer music, electronic music and electro-acoustic music are all terms for new forms of music concerned with the design of evocative and beautiful sounds using electronic technology and less with traditional musical structures such as rhythm and melody. Electroacoustic composers work with sound in ways which allow it to be modulated as it is created. In other words, the way that a dancer moves can be used to modify the way that the music sounds. This implies that the music is not simply triggered by the mover, but in some sense "played" by their movements. A parallel development in choreography is seen in the freer definitions of dance, including such things as task-oriented movement, non-virtuoso movement and freedom from story telling or classical references.

Together these artistic developments offer heretofore little-explored worlds of creative possibility in which music-making and dance-making are not inherently limited by body type or disability. It was thus our intention from the outset to work with music and movement constructs of high quality and innovation. ix.

4 Procedure

4.1 Analysis of impairments

Cerebral Palsy takes many forms and ranges widely in severity. In addition, musical taste and ways of moving are idiosyncratic. Thus, we needed to have a number of different approaches in order to find systems appropriate to each subject. This implied the need to analyze in advance each child's condition so that some groupings could be made according to which mapping would have the strongest response, i.e. engage the subject's interest. The following aspects were analyzed:

- Degree of control and freedom of movement particularly in:
  - arms
  - legs
  - head and face
- Ability to communicate (including oral and non-oral ability)
- Response to music, musical, gestural and dance preferences
- Additional disabilities such as hearing or speech impairment

These evaluations were made in the weeks leading up to the motion tracking sessions and included information from physiotherapists, speech therapists, psychologists and other therapists who work daily with the children. Subjects were finally placed into one of five groups. This grouping allowed us to work with similar cases at the same time range, helping to optimize sensors and software. The groups were made attending to physical abilities, age and cognitive capacity. The five groups were the following:

1. Those who could walk unassisted
2. Those under 4 years old with good cognitive functions
3. Those between 13 and 16
4. Those with good cognitive ability, but were in wheel chairs
5. Those with severe movement limitations and additional cognitive disturbances

4.2 Technology used

We used the motion tracking software EyeCon(5) running on a 3.2 GHz portable PC computer (WindowsXP). We attached two kinds of sensors to it. The first was a video camera with a high resolution (1/2") CCD image sensor. This is a standard surveillance camera and fits easily in the palm of your hand:
Figure 1: Standard CCD video camera.

The second was a custom designed electrode system which we use to sense body contact between two or more persons (touching completes an electrical circuit).

Figure 2: Custom-made ankle- or wrist-worn electrodes.

The real time sound processing was done within the EyeCon software itself, though for many mapping this is not possible. (See Table 1: Available Mapping Parameters.)

4.3 Description of motion tracking software program

In contrast to many interaction-oriented digital media systems, EyeCon is not freely programmable, i.e. does not work like a programming language. Rather it is based on the fixed architectural elements described above. Instead of creating entire environments with highly accurate and specialized properties, EyeCon is conceived in terms of dynamic control -- both spatially (movable shapeable elements) and temporally (sequencer functions). The result is a relatively intuitive system for performers and artists which, by its nature, is relatively easy to operate. A person with little or no computer experience can learn to use it within a few hours.

The EyeCon software can be divided in two completely different parts: motion tracking and multimedia control. EyeCon allows you to create motion sensing elements which are graphically represented as lines, rectangles and other objects. The element editor is the main mapping panel where you assign how movement controls media.

Figure 3: The user interface of EyeCon 1.60.

EyeCon has two operating modes, simulation and run mode. In run mode the actual video analysis is performed and media is played. In simulation mode you can use tiny boxes and move them with the mouse to emulate moving objects in the video image. The control window allows you to control the main parameters of the video processing like camera selection, threshold for movement detection, basic timing etc. The video window allows you to
watch the live video and see how the motion sensing elements react.

To allow the creation of complex interactive setups, EyeCon offers a scene management function. Each sensing element is functional in a selectable level. The sequencer window allows you to arrange these interactive setup levels.

4.4 Input

As mentioned above, we used the EyeCon motion tracking software with two types of input, reflecting two types of sensors, electrodes and video:

A. Electrode sensors

A custom-made electrode-based system was used to determine if two people are touching or not. A small electrical current flows between the two people, completing a circuit and causing EyeCon to trigger a media change.

We made elastic ankle bands with Velcro closures, one of which was worn by the therapist and the other worn by the subject. This allows both therapist and subject to quickly forget the wiring (although it obviously does still limit one's ability to run around the room). Additional people can join the circuit, for example, one therapist might touch another, who in turn touches the child.

This system offers a discreet (Boolean) control parameter, i.e. on and off. I.e. two people are either touching or they are not. The limitations of the system meant that different types or qualities of touch cannot generate different sounds and that the system cannot be made to react to body parts differently.

B. Video camera sensors

The video approach can be used with continuous as well as discreet mapping parameters and offers a variety of mapping possibilities (see 3.6 Mapping, below).

A video signal is fed into the computer and the video image appears on the computer screen. Using the mouse, elements in the form of lines or fields in different colors are superimposed onto the video image (see figure 1). When a subject moves through one of these elements, that is, when their video image touches or moves within one of the lines or fields, a media event is triggered (for example, a certain sound might be heard) or modulated (for example, a sound we are already hearing might become louder or higher pitched).

EyeCon works by a process known as background subtraction. By comparing the light intensity or color values of given pixels on two different video frames, we can see reveal where movement or position changes have taken place. The eyecon software allows frame comparisons (subtractions) to be made in one of two fundamentally different ways:

Method 1: with fixed background

In this method, a video frame stored in memory (essentially a photograph of the room when no one is in it) is compared to the current frame. Essentially, this method allows one to detect changes in position or shape, e.g.:

1. presence/absence of body part at a given location in space
2. movement of a body part up and down
3. movement of entire body up and down (i.e. measuring the highest point on the body)
4. changes in shape
5. position left-to-right across the room
6. width
7. degree of contraction or expansion in the body
8. tracking the position of a person in the room (assuming you have a high overhead camera)

Method 2: without fixed background

In this method, the current video frame is compared to the previous frame. Essentially, this method detects motion, for example:

1. stillness (as trigger)
2. action following stillness (as trigger)
3. activity level at defined zones (for example for different body parts)
4. total body activity-level
5. total activity-level for a group of people
6. direction of travel left-right
7. direction of travel up-down

4.5 Output

Although EyeCon can provide different kinds of media responses (including light control, video projection control, etc.) sound properties were the most suitable
for this project. EyeCon offers the following sound processing capabilities:

1. note
2. scale
3. melody
4. single short musical sounds, recognizable sounds (animals, devices), words
5. text, poetry, prose
6. music (in the traditional sense, with rhythm, melody, etc.)
7. textural sound (often continuous, often ambient, in any case non-traditional music)
8. volume change
9. pitch change
10. panning (left/right)

Using additional external software it is also possible to control:

1. filtering
2. sound scrubbing
3. DSP (Digital Signal Processing), such as granular synthesis, phase vocoding, etc.
4. Advanced DSP, such as particles clouds, etc.

Thus in practice EyeCon is often used to control secondary programs either running on the same machine or in another computer liked to the first via data link or ethernet-based network. The data transfer takes place either via MIDI or OSC protocol. External software and hardware which can be controlled by EyeCon include software and hardware synthesizers, as well as programs such as Director, MAX/msp, Reactor, SuperColider and Isadora.

This way of using EyeCon provides a far greater number of sound control parameters to be controlled in real time. The point is not that more sophisticated music can be played using these additional tools, but that the music used can be manipulated in more interesting and ultimately more attractive ways.

4.6 Mapping

![Diagram](image)

**Figure 4: Model for interactive performance system.**

The inter-action or back-and-forth in this system occurs as the humans involved are affected by the media which they have influenced (indicated by the red arrow above). In other words, music makes us dance. Or, just as,

![Diagram](image)

*Mapping* (see Figure 2, *Mapping*) is a theoretical construct comprised of input, output and the relationship between the two (in other words, the conditions of their causal relationship).
The number of possible mappings in any given interactive environment is typically very large. Not only are there numerous parameters of movement and sound, but there are many ways in which a given input parameter can be causally related to an output. These relationships include:

1. trigger (positive) action = on, absence = off
2. trigger (negative) action = off, absence = on
3. toggle
   - for example, presence or action = on, absence or stillness = no change
   - subsequent presence or action = off, subsequent absence or stillness = no change
4. iteration
   - for example, going stepwise through a musical scale or melody, a series of words, or simply a sequence of musical samples
5. continuously variable (positive) increasing input = increasing output, etc.
6. continuously variable (negative) increasing input = increasing output, etc.
7. trigger used as a delineator for a system change
8. random changes

The number of possible mappings is represented by the equation:

\[ \text{inputs} \times \text{outputs} \times \text{relationships} = \text{mappings} \]

or,

\[ I \times O \times R = M \]

As discussed above, our study contained a total of 16 inputs (15 using video sensor and 1 using touch sensor), 14 outputs, and 8 ways of relating the two, or,

\[ 16 \times 14 \times 8 = 1792 \]

The conundrum is to find the ones that can deliver a palpable or intuitive response. The vast majority of mappings are simply not noticeable, or, more to the point, palpable.\textsuperscript{ix} That is, there are many mappings which are noticeable if they are pointed out to us, but very few which a person (handicapped or not) feels intuitively or kinesthetically -- through the body in motion.

In our study we used ten different mappings (see Tables 1, 2 and 3).

When we make a certain movement, and at that same moment we hear a sound, and this occurs repeatedly, then there is some likelihood that we will feel that something causal has occurred -- that our actions have become endowed with a power that they do not normally have. This response can be quite instinctive -- it does not need to be understood in order to be felt. In our mind, the action and sound become linked. In our perception they can form an integrated experience.

The most important property of an interactive system is synchronicity. If there is a latency between the action of sound of more than 100-200 ms then there is a noticeable lag and one begins to lose the kind of integrated experience we just mentioned.\textsuperscript{xii}

Some mappings which are difficult to understand may nevertheless be strongly felt. Whether easily understood or not, as artists and therapists we are interested in mappings that illicit strong intuitive responses.
5 Results

We analyzed our results according to the type of mapping used, subject's apparent level of engagement and our general observations and impressions. (See Table 3: Sample results with examples on video).

The video time codes listed refer to the video clip hh1.avi (it has been uploaded in compressed form to http://www.palindrome.de/CP.

The analysis of the videos showed different results depending on the mappings and on the children's characteristics:

Mapping code 8, I-O-R: 2-2-4. Moving the body up and down converts into a piano scale.

This mapping had good results with people with higher cognitive level. Both people with fast and slow movements showed engagement in the experience.


It was very useful for people with very small residual movements as a very subtle change triggers the action.


This mapping was effective in children that had the capacity to stop movement completely and restart movement in a strong manner. It was effective with people with high and low cognitive level as it constitutes a very intuitive mapping.


This mapping was effective exclusively with children with good cognitive level as it requires certain consciousness of own movements. It was very motivating.


The use of the touch sensor was more efficient with younger children as it allows an emotional contact with the therapist. Physical contact related to music creates a very intuitive response.


This mapping was effective for children with good cognitive level when it was taken as a game so it needs a certain link with the therapist.

Other results extracted from the analysis of the videos were:

- Children's musical preferences were crucial as the music the children already knew and liked showed better results of engaging.
- The cognitive level of the participants was relevant. The children with a higher cognitive level were more conscious of the interactive system and thus more quickly and thoroughly involved in the experience.

Meanwhile, the children suffering the more severe physical limitations were the group in which we saw the most impressive reactions. These children are not used to acting without assistance but in this case their movements produced a response, even while their gestures were in some cases hardly noticeable to those around them.

6 Conclusion

It must be noted that our experiences were very limited. We worked with subjects for a very short time. Both we, and our subjects need more experience to fully understand what the potential of such systems might be. The exploration of the interactive environment -- the discovery of its capabilities and limitations -- requires more time and further trials.

However, the experience was very successful. In the first place, we must note that the mere fact that movement creates sound is useful in working with handicapped people. In other words, the fact of this unusual relationship is alone sufficient to engage people and stimulate movement.

Beyond this, the fact that technology can be adapted to each subject's characteristics constitutes an important approach to understanding music, dance and art performance with handicapped persons.
Given the right adaptations, anyone can express themselves artistically. Persons with physical limitations can thus find ways of becoming more autonomous and creative within artistic performance settings.

Finally, there is the general feeling of empowerment which results from using the body successfully to control one’s environment. There is an inherent pleasure and sense of confidence in one’s body which we witnessed in the faces of and actions of the subjects.

Children with lower cognitive level can benefit from the intuitive feedback that sound provides for their movements. For children with higher cognitive level, movement becomes intentional and through a trial-and-error process, a self-training is possible. As with any musical instrument, with the right training, new ways of playing music result.

It must be noted that our experiences were very limited. We worked with subjects for only two days and only had approximately 20 minutes per subject. Both we, and our subjects need more experience to fully understand what the potential of such systems might be. The exploration of the interactive environment -- the discovery of its capabilities and limitations – requires more time and further trials.

7 References


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8 Tables

Table 1: Available Mappings
Table 2: Preferred Mappings
Table 3: Sample results with examples on video

9 Endnotes

i Robert Wechsler is a choreographer, dancer and interaction designer. MFA in choreography from New York University. He is director of the Palindrome Intermedia Performance Group, www.palindrome.de.

ii Alicia Peñalba is a doctor in musicology, a music therapist, a speech therapy and a flute performer. She teaches music therapy at University of Valladolid and has worked with handicapped people since 1998.

iii Centers for Disease Control and Prevention, Dept. of Health and Human Services, USA, www.cdc.gov.


v This type of motion tracking has been the stalwart of the performance group Palindrome (www.palindrome.de), which is directed by one of the authors. Palindrome were early developers of such interactive performance systems and are designers of the EyeCon system which was used in this study. vi http://www.asprona-valladolid.es/obregon/

vii The term patch originally meant a piece of computer code written to repair a bug. Today, it is often used to mean the groups of settings written in a program that can be saved and used later.

viii Perlan Theater Group, Iceland; CandoCo Dance; Company; Art Spider; CandoCo Dance Company Cando II; Common Ground Sign Dance Theatre; Dada South; Heart ’n soul.

ix Sounds we used included those composed by Dan Hosken, Butch Rovan and Pablo Palacio as well other commercial songs. The authors themselves are a musician and a dancer.

x Some of these may be impossible for technical reasons, but needless to say, the number is very large.

xi There are no studies that we are aware of on the palpability of interactive movement-to-sound mappings. We are relying on personal experience. Together with Palindrome Dance Company, Wechsler has been exploring these possibilities with professional dancers since 1985.

xii This conclusion is derived from personal experience.