

Music Access for the Disabled

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PART 1: INTRODUCTION

1. Introduction

This project grew out of a meeting between Charlie Hogg and Simon Gunton in 2005. Charlie was the student representative of Engineers Without Borders¹ in Cambridge, and Simon is a composer and an employee of a charity called Escape Artists. Established in 1996, Escape Artists exists to bring the arts to marginalised groups, including people in prison and people with disabilities. The outcome of the meeting was the idea that computer technology might help the severely disabled to express themselves through music.

2. Purpose of the Project

2.1 *Meeting with Simon Gunton, 17/6/05*

My first meeting with Simon was on 17th June 2005. I went with him to the Music Faculty in West Road to observe one of his workshops in action. As part of his work for Escape Artists, Simon organises and runs regular music workshops for people with mental and physical disabilities. The one on June 17th was for people with a mental handicap. A dozen or so people attended, I joined in, and Simon led us in the composition of a piece inspired by the work of Charles Darwin. He was aided by a Cambridge undergraduate musician and a colleague from Escape Artists, who recorded the event on film.

Simon is extremely good at leading music workshops. He was well prepared with instruments to suit all abilities, some more colourful than functional, and knew exactly what he wanted to achieve. His tireless enthusiasm motivated the attendees to express themselves creatively. He gave them each a spotlight in turn, and each rose to the occasion. I have no doubt that his ongoing efforts to bring music to the disabled have a lasting impact on their lives.

After the workshop, Simon and I discussed his work at the Sue Ryder Care Centre in Ely. At Sue Ryder, all the residents are wheelchair-bound, and most have seriously restricted movement in their upper bodies. Some are unable to speak. Simon has tried to run similar workshops there, and has had some success. However, he has been repeatedly frustrated by

¹ EWB is a global organisation, and Cambridge is the centre of UK operations. Further information is available from <http://www.ewb-uk.org/cambridge>

the limitations of the instruments he uses. Some attendees of his workshops at Sue Ryder can do little more than tap on a woodblock, and some cannot even do this unaided. Simon was convinced that they were capable of using music for more subtle self-expression, and was looking for a way to make it happen.

Eager to explore the route of computer technology, Simon described to me his two goals for the project. The first was to enable each member of his workshop group at Sue Ryder to contribute to a piece of music, in individual tracks which could be layered together. The second (and higher) goal was to create a Sue Ryder band.

2.2 *Simon, Allan and Mali*

As the project progressed, it became clear that we needed to focus our efforts on a small number of individuals at Sue Ryder. Simon decided to choose three who were young and eager to take part in his workshops, but who were highly restricted by physical disability.

Simon, Allan and Mali were chosen. Simon and Mali have almost no movement below their necks, except for a small amount in one arm in both cases. Simon can move his left arm, and open and close his left hand, but has little control over the independent movement of his fingers. Mali can move his right arm a little, but the only movement in his right hand is of his thumb, and only over a distance of about 5mm. Simon is fully mobile above the neck, although he cannot speak. Mali has restricted head movement, but has good control of his eyes and blinking. Allan has Huntington's disease, so whilst he is much more mobile than Simon and Mali, and can walk and speak, his involuntary movements make it difficult for him to contribute to the music workshops.

My work with these three men is discussed in detail in part 3. To avoid the confusion that could arise from having two of the four significant players in this project called Simon, I shall hereafter refer to the composer from Escape Artists as Simon Gunton.

2.3 *Specifications*

Throughout the first weeks of the project, I assembled a list of requirements for the prototype electronic musical instrument I was to design. This was done through conversations with Simon Gunton and others (see section 6). The specification is as follows:

- An instrument that will enable creativity in those whose bodily functions are limited.
- A means of enabling Simon, Allan and Mali to express themselves.
- A means of allowing for subtlety in musical performance which is not possible with current instruments.
- A system that can be operated by anyone with basic computer skills.
- A set-up time of less than thirty minutes, for eight users.
- A system that can be packed up in a similar amount of time and easily moved.
- Size not to exceed 0.3x0.3x0.6m.
- Weight not to exceed 5kg.
- Easy and fun to learn.
- Instant musical results on the first use.

3. Existing and Emerging Technology for the Disabled

3.1 Resources for the disabled

In the UK there are a number of organisations and charities that specialise in providing disabled people with technologies that will improve their quality of life. Two extremely good resources for finding such organisations are Pat Saunders' *A-Z of Disability*² and J. Barrett's *Communication and Access to Computer Technology*.³ Two of the organisations they list are of particular interest to this project. These are as follows:

Shape Arts, providing funding for disabled people in the arts. www.shapearts.org.uk

Remap, a network of volunteer engineers and craftsmen, who make free one-off aids for disabled individuals. www.remap.org.uk

3.2 Development of computer controllers for the disabled

A great deal of work is being done in the field of computer controllers for the disabled, and a very large number of products are commercially available. I have arranged them into five categories: contact movement, non-contact movement, breath activation, sound activation, and direct brain activity. Within each category the methods of human-computer interaction appear in order of increasing commercial cost. Since Escape Artists is a charitable organisation, keeping costs low is important. Any piece of equipment over \$100 would have to be extremely good to be considered.

(i) Contact Movement

- Mouse (\$10) converts arm motion into pointer motion. Widely available. Unlikely to be of any use in this project.
- Joystick (\$20) registers hand position and wrist orientation. Widely available. Unlikely to be of any use in this project.
- Keyboard (\$30) is a large array of simple switches. This has been found to be impossible to use for those at Sue Ryder.

² Pat Saunders, *A-Z of Disability* (Crowood, Marlborough, 1989).

³ J. Barrett, *Communication and Access to Computer Technology* (Disability Information Trust, Oxford, 1995).

- Simple mechanical switches for the disabled start at around \$40. There have been switches designed to respond to almost every type of movement. Switches can be two-state (on and off) or multi-state. There are a number of Internet retailers, such as www.enablemart.com. Simple switches have a great deal of potential for this project, but would have very limited use unless they were coupled with more complex devices.
- Mouth joystick (\$500) converts head motion into pointer motion. An example of a mouse joystick can be seen on the Ability Corp website.⁴ These are too expensive and too clumsy to be useful to this project. They do not allow for the subtlety of human-computer interaction required to make music.



(ii) Non-Contact Movement

- Computer vision software is available at the department of engineering free of charge from the Vision group. The system needs only a USB2 camera (\$100) and can translate motion into pointer movement. The software has been designed so that movement of any facial features can be tracked, including eyes, eyebrows, eyelids and mouth. This is an extremely promising avenue.
- Infrared reflection technology starts at around \$300. The principle is that an infrared beam is transmitted from above the computer screen. This beam interacts with a reflective dot somewhere on the user and returns to the transmitter. Based on the location of the reflected signal, the computer registers the movement of the reflective dot and translates this into pointer motion. One such system is the SmartNav, pictured left.⁵ In SmartNav, the reflective dot is located on the peak of a baseball cap, and so the system translated head motion into pointer motion. Since Allan and Simon both have good control of their head movement, this is another promising option.
- I/S/T switches (\$395) are the latest technology to be utilised by Professor Stephen Hawking. I/S/T stands for Infrared/Sound/Touch; the system can be adapted to register any of these input signals.⁶ Professor Hawking uses infrared



⁴ Ability Corp website: http://www.abilitycorp.com.au/html/Ability_Mouth_Controls.htm

⁵ SmartNav is available from NaturalPoint: <http://www.naturalpoint.com/smartnav/>

⁶ More information on I/S/T switches, and the possibility of purchase, is available at <http://www.words-plus.com/website/products/input/istswtch.htm>

reflection from the muscles below his eye to communicate with his computer. Unfortunately, this is too expensive for our purposes.

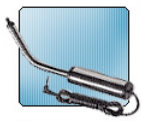
- Ultrasound can also be used to make music. This is demonstrated in a device called Soundbeam: see www.soundbeam.co.uk. Soundbeam converts human motion of all kinds into music, but it costs about \$800, and so is not a viable option for this project.

(iii) Breath Activation

- The Yamaha Breath Controller (\$80)⁷ is a MIDI (Musical Instrument Digital Interface) device for converting breath into computer signals. It registers fine variations in air pressure and allows for more realistic playing of brass and woodwind instruments on a computer. At first this seemed like a promising piece of technology for use in this project, but it turned out that none of the people we are working with have sufficient control over their breathing to use it.



- Sip/puff tubes (\$300) are widely used by quadriplegics to control their wheelchairs. These are two-state switches, and are widely available from websites such as www.ergoguys.com. Again, these seemed promising initially, but are not an option for this project due to insufficient breath control.



- To make this list as comprehensive as possible, I will include an idea that the Inference group in Cambridge has developed, though it is not yet available commercially. The group has designed a system to convert lung volume into pointer motion using an elastic belly-belt. The details of this idea are available online.⁸

(iv) Sound Activation

- Sound activated switches (\$40) are two-state devices that respond to a loud and sudden sound, such as a clap. These are impractical for music performance.
- Voice recognition systems are also available, and these can convert verbal commands into computer functions. These are similarly impractical for musical performance.

⁷ The Yamaha Breath Controller can be purchased for this price at

<http://www.zzounds.com/item--YAMBC3A>

⁸ Details of the system: <http://www.inference.phy.cam.ac.uk/dasher/development/Breathing.html>

(v) **Direct Brain Activity**



- The non-invasive method of measuring brain activity is through the EEG (electroencephalographic) cap (\$500). This is still a developing technology, but it is possible to stick sensitive electrodes to a person's scalp and detect brainwaves. These can subsequently be converted into computer signals. This system might hold some exciting potential for electronic music generation, but is too expensive to be explored as part of this project.
- The invasive method of measuring brain activity is the brain gate (\$25000), a direct link between brain and machine. The system requires an operation to implant a 2x2mm array of 100 electrodes in the motor cortex beneath the skull. Once this array is connected to a computer, it is then possible to control a mouse, and many other devices, just by thinking. The system is in its infancy, and has no bearing on this project, but is included for comprehensiveness.⁹

In summary, the only available technologies that might be useful in allowing Simon, Allan and Mali to perform music are mice, joysticks, simple switches, computer vision software, and infrared reflection. Some combination of two or more of these will almost certainly be required.

3.3 Music access for the disabled

Research into new ways of performing electronic music is being undertaken all over the world, and much of it has a direct bearing on this project. Here are six examples of what is being developed in London, York, Boston, Princeton, Barcelona, and Helsinki.

London: The Drake Music Project (www.drakemusicproject.org) was established in 1988 to enable children and adults who are unable to play conventional musical instruments to discover their musical abilities. The project is committed to helping such people explore, compose and perform their own music. The Drake Music Project has utilised and developed various bits of computer hardware and software in order to fulfil its aim. One of these is a program called E-Scape, which allows a user to compose a piece of music of multiple layers

⁹ Articles & videos on the brain gate: <http://www.paralinks.net/quadconnection/braingateforquads.html>

and instruments using only two switches. A demo version of this ingenious and effective program may be downloaded online.¹⁰

York: The University of York Department of Electronics has a research centre devoted to music and disability. Dr. Andrew Hunt¹¹ has a special interest in human-computer interfaces, particularly in relation to musical instrument control. Mr. Ross Kirk¹² has special interests in computer architecture for music technology, music synthesis techniques, instrument design, and electronic systems for the disabled.

Boston: MIT has a course on electronic musical instruments, with lectures given by Steve Banzaert.¹³ The students on this course use a variety of technologies to build electronic instruments for autistic children. Steve makes use of MIDI technology and MIDI controllers to do this. MIT also has a group that works on experimental instruments, such as the Beatrix, the flexi-doods, and the bass trumpanet.¹⁴

Princeton: Princeton University also has a specialist in computer music. Associate Professor Perry Cook¹⁵ specialises in computer science and electronic music. He has focussed a good deal of attention on the problem of making digital instruments feel and sound more like the real thing. He has also sought ways of giving performers more freedom of expression with digital instruments. He is the joint leader of the Princeton Laptop Orchestra (PLork), established in 2005. In this orchestra, student performers upload and arrange pre-programmed loops to create a sound that would be impossible without computers. In his 2004 article, Professor Cook demonstrates the importance of auditory and haptic feedback paths in electronic instruments.¹⁶ Haptic is the term used to describe the combined senses of touch, including skin vibration and pressure, and the muscle senses of motion, position and force. A woman playing a violin, for example, has the haptic feedback of the vibrating bow in one hand, the string in the other and the instrument against her shoulder. She also receives the auditory feedback directly from the string, as well as the reflection of the sound off the walls

¹⁰ For E-Scape demo, go to <http://www.drakemusicproject.org/4descape.asp#downloads> & scroll down.

¹¹ Dr. Hunt's contact details are available at <http://www.elec.york.ac.uk/staff/academic/adh.html>

¹² Mr. Kirk's contact details are available at <http://www.elec.york.ac.uk/staff/academic/prk.html>

¹³ Mr. Banzaert's contact details are available at <http://web.mit.edu/Edgerton/www/Banzaert.html>

¹⁴ All these instruments can be found at <http://web.media.mit.edu/~vigoda/pemi/pemi.html>

¹⁵ Professor Cook's contact details are available at <http://www.cs.princeton.edu/~prc/>

¹⁶ Perry R. Cook, "Remutualizing the Instrument: Co-Design of Synthesis Algorithms and Controllers," *Journal of New Music Research* 33 (2004): 315-320.

of the room. Electronic instruments don't have nearly as many feedback paths, and this, argues Professor Cook, gives rise to a loss of intimacy between the performer and the instrument. The result of this loss is that the instrument is harder to learn, and the performer is never able to be as expressive, leading to poorer quality performances. The solution he proposes is to fight against the historical tendency to abstract the controller from the synthesiser and build more integrated instruments.

Barcelona: Sergi Jordà is associate Professor at the Pompeu Fabra University of Barcelona. He has worked extensively in the field of visual feedback for computer music systems. At the 2003 Stockholm Music Acoustics Conference he delivered a presentation entitled "Interactive Music Systems for Everyone."¹⁷ In this paper, Professor Jordà describes his progress in the development of an electronic instrument that is both simple to use and sophisticated, returning an output more complex than the input it receives. The result is a piece of software called FMOL (Faust Music On Line) and can be downloaded free of charge.¹⁸

Helsinki: The Helsinki University of Technology has made a number of contributions to the development of electronic music; the most recent is the Virtual Air Guitar (*right*). Players put on a pair of brightly coloured gloves and pretend to play the guitar. The computer detects the positions of the gloves and adds sound.¹⁹ This is a great example of creativity in computer music control.



4. The Generation of Electronic Music

4.1 Theory

Much detailed and technical study has been done on this topic, but for the purposes of this project only a cursory overview is required. I shall first consider the decisions made by a traditional musician, using the example of a trombone player, and then explore how these can be mimicked by electronic instruments. A traditional musician might make any of the following choices in sounding a single note:

¹⁷ Sergi Jordà, "Interactive Music Systems for Everyone: Exploring Visual Feedback as a Way for Creating More Intuitive, Efficient and Learnable Instruments," *SMAC 2003*. This presentation can be read online at <http://www.iaa.upf.es/~sergi/articles/smac03jordada.pdf>

¹⁸ FMOL can be downloaded at <http://www.iaa.upf.es/~sergi/FMOL>

¹⁹ New Scientist report on the Virtual Air Guitar: <http://www.newscientist.com/article.ns?id=dn8383>

(i) **Beginning the note**

- **Pitch:** the trombonist selects the frequency of the note to be played by setting the trombone slide and also by deciding how hard to blow.
- **Volume:** this is controlled by the velocity of air passing over the lips.
- **Attack:** the attack of the note is one of the most important considerations. The trombonist must decide how rapidly the note reaches maximum intensity, determining how “hard” or “soft” the note sounds. Note attack is one of the most distinguishing features of musical instruments, and if a recording is edited to remove the attack portion, it often becomes very difficult to identify which instrument is playing.²⁰

(ii) **Sustaining the note**

- **Volume:** The note may be sustained at constant volume, or may grow gradually louder or softer.
- **Vibrato:** A very slight changing of the pitch of the note, alternately above and below true pitch, can be achieved by small, high frequency oscillations of the slide.
- **Tremolo:** The rapid repetition of a note is possible with stringed instruments, but not in the case of the trombone.

(iii) **Ending the note**

- **Note Length:** the musician can choose whether to play notes very short with a brief silence in between each (staccato), or longer with almost no silence in between (legato).
- **Portamento:** this is the effect produced when one note is carried smoothly onto the next with no gap. The trombonist can achieve portamento by maintaining the breathing, and moving the slider to change the pitch of the note. All the pitches in between the two notes are sounded briefly. The portamento time is the time taken to transition completely from one note to the next.

²⁰ Richard Dobson, “Attack”, in *A Dictionary of Electronic and Computer Music Technology* (Oxford University Press, Oxford, 1992).

All of these effects can be simulated by MIDI controllers. The most common controller for selecting pitch and volume is the electronic keyboard with pressure-sensitive keys. The performer selects a key to determine **pitch** and can choose the force with which to press it, fixing **volume**. The keyboard is usually equipped with a large number of instrument sounds. The pre-selected sound determines the note **attack**, whether or not the note **volume** decays, and any **vibrato** or **tremolo** effects. Finally, note **length** is controlled by the timing of the release of the keys. With this simple arrangement, the keyboard player has no control over note attack, decay, vibrato or tremolo at the time of performance, but can set these variables in advance.

For greater control over these parameters, additional MIDI controllers are required. Two such controllers are the pitch bend wheel and the breath controller. The pitch bend wheel is a common addition to the basic keyboard, and provides real-time control over vibrato and **portamento**. The breath controller allows the performer to vary the volume of the note as it is played by blowing into a mouthpiece. It can also be used to add vibrato and tremolo to the note.

These are the controllers used by the able-bodied to perform music on electronic instruments. The challenge of this project is to provide the disabled with control over the same parameters. I have shown in section 3.2 that this will involve the creation of a computer interface that enables the user to determine note pitch, volume, attack, decay, vibrato, tremolo, note length, and portamento using some combination of mice, joysticks, simple switches, computer vision software, and infrared reflection.

4.2 History

Today the electronic keyboard is the most popular MIDI controller, but it is almost totally inaccessible Simon, Allan and Mali. I took a brief look at the history of electronic instruments²¹ to see if anything had been developed that might be more useful to them.

²¹ All historical information is from http://www.obsolete.com/120_years/

1876: Elisha Gray invents the Musical Telegraph (*right*), the first electronic instrument. It is keyboard controlled, amplified by the telephone system, and has a range of two octaves.



Duddel's Singing Arc (**1899**), Cahill's Telharmonium (**1897**), and Severy's Choralcello (**1909**) were also keyboard controlled, and so of no interest to this project.



1917: Leon Termen invents the Theremin (*left*). Termen sought to free the performer from the keyboard and fixed intonation by making use of the influence of body capacitance on the heterodyning effect between two high frequency sound waves. Moving the right hand alters pitch, and the left changes the volume. The idea is of some interest to this project.

1921: Jorg Mager invents the Electrophon. This has no keyboard, but is instead controlled by means of a handle that the performer moves over a marked semicircular dial. This creates a continuous glissando effect, and is an interesting method of control, but has limited potential for this project. With computer technology, it should be possible to do far more exciting things with this kind of motion.

1928: Maurice Martenot invents the Ondes-Martenot (*right*), based on the ideas of Leon Termen. The performer manipulates a string attached to a finger ring to create a sound in a way similar to the Theremin. Martenot's aim is to produce a versatile instrument that is immediately familiar to orchestral musicians. His invention, like the Theremin that inspired it, is of interest in this project.



After 1928, the majority of electronic instruments invented were played with a keyboard. There were also several more derivatives of the Theremin, such as the Sonorous Cross (1929). Much later than this, electronic instruments started to be developed that mimicked orchestral instruments. These are of no interest to this work, since Simon, Allan and Mali cannot play them. Thus, the only historical development that has any bearing on bringing music to the disabled is the Theremin. However, it is probable that Soundbeam (described in section 3.2) is a more effective way of turning motion into music, but this has already had to be eliminated from consideration due to its high cost. The conclusion is that, in this case, there is little from the history of electronic music that can be directly applied to this project.

4.3 Available resources

To finish off this cursory discussion of the generation of electronic music I will mention two excellent computer programs. The most effective way of generating exciting sounds quickly is by means of pre-programmed loops, as in the Princeton Laptop Orchestra (described in section 3.3). There are many programs available that provide this facility, but the Apple program **GarageBand** is still one of the best.²²

In seeking to enable Simon, Allan and Mali to play music, I deliberately avoided the pre-program route as far as possible. I thought that an alternative route would provide them with more creative freedom, and also wanted to explore options that had not been developed very much before. The program I used to make computer music was **Max/MSP**.²³ This is an advanced DSP (digital signal processing) platform that enables the design of MIDI programs from scratch. Max/MSP is very powerful, and is capable of simulating all the musical effects described in section 4.1.

5. The Abilities and Limitations of the Musician

5.1 Mapping the capabilities of parts of my body

In seeking the best means of communication between a disabled person and a computer, I ventured into the study of quantifying disability. Simon, Allan and Mali have little or no movement in certain limbs, but seemingly full movement in others. It was necessary to determine whether or not the movement they have in these limbs is as full as that of an able-bodied person. I conducted an investigation in order to find the best way that each of them could communicate with a computer.

This investigation began with a study of the abilities of my own body, in order to provide a means of comparison. I conducted two simple tests: how many times a second I could activate a switch (the frequency test), and how closely I could follow a given beat (the accuracy test). I wrote a computer program to run each test. The first program simply counted the number of button clicks it received in a twenty second period and calculated the average number of clicks per second in Hertz. The second program consisted of a metronome beating out a bar of four at a tempo set by the user. The user was required to click a button on the third beat of the

²² Details and download of GarageBand at <http://www.apple.com/ilife/garageband/>

²³ Details and download of Max/MSP at <http://www.cycling74.com/products/maxmsp>

bar. The computer measured the time difference in milliseconds between the button click and the actual beat. It took twenty readings and output the last fifteen, giving five bars for the user to adjust to the tempo.

Table 1 shows the average of all my frequency test results, and table 2 shows the average of all the accuracy test results. As far as possible, I measured only one movement in each of the tests. For the index finger test I laid my hand flat, palm down on a table and moved my finger up and down. For the wrist test I held my forearm still and hit a switch on the table with my thumb, keeping my thumb joints still and rotating my wrist. For the arm test my elbow stayed on the table, and for the foot test my heel stayed on the floor. The three head tests were not done with switches, but with a SmartNav (which is described in section 3.2, part (ii)).

AVG. FREQ (Hz)	Index Finger	Wrist	Arm	Foot	Head LR	Head FB	Head LFRB
Right	6.76	6.70	7.01	4.99	2.31	3.16	1.54
Left	6.27	6.06	6.74	4.15	-	-	-

Table 1: Frequency test results.

AVG. ACCURACY (ms)	Index Finger	Wrist	Arm	Foot	Head
Right – Mean	-9.00	11.27	14.00	-2.40	-14.53
Right – Standard Deviation	24.05	33.34	24.19	22.84	44.13
Left – Mean	-0.80	-12.60	5.31	11.73	-
Left – Standard Deviation	25.33	18.80	24.49	21.35	-

Table 2: Accuracy test results.

The results in tables 1 and 2 show that there is almost no difference between the frequency or accuracy abilities of my fingers, wrists and arms on either side. My right arm is marginally faster than anything else, and my left wrist is marginally more accurate. My feet lag behind in frequency, but not in accuracy. My head lags behind in both frequency and accuracy.

So far I have only considered motion between two distinct states. However, some limbs are capable of selecting between more than two states. In order to extend my tests to include bandwidth (proportional to the number of bits it is possible to chose from) I performed an experiment similar to that from which Fitt’s Law arose. I measured the frequency at which I could move the tip of a pencil between two points of fixed distance apart. Having completed ten cycles, I measured the distance between the target and the outermost pencil mark. This was my maximum error in mm. I converted this error to a percentage of the distance between the points, and then took the reciprocal. This yielded a simple estimate of the number of bits I could reliably select from at that frequency. The results of this test are included in graphical form in figure 1. I have added the values of my right finger and foot (both two-bit devices) to this graph, and also my head (a four-bit device: left, right, front and back).

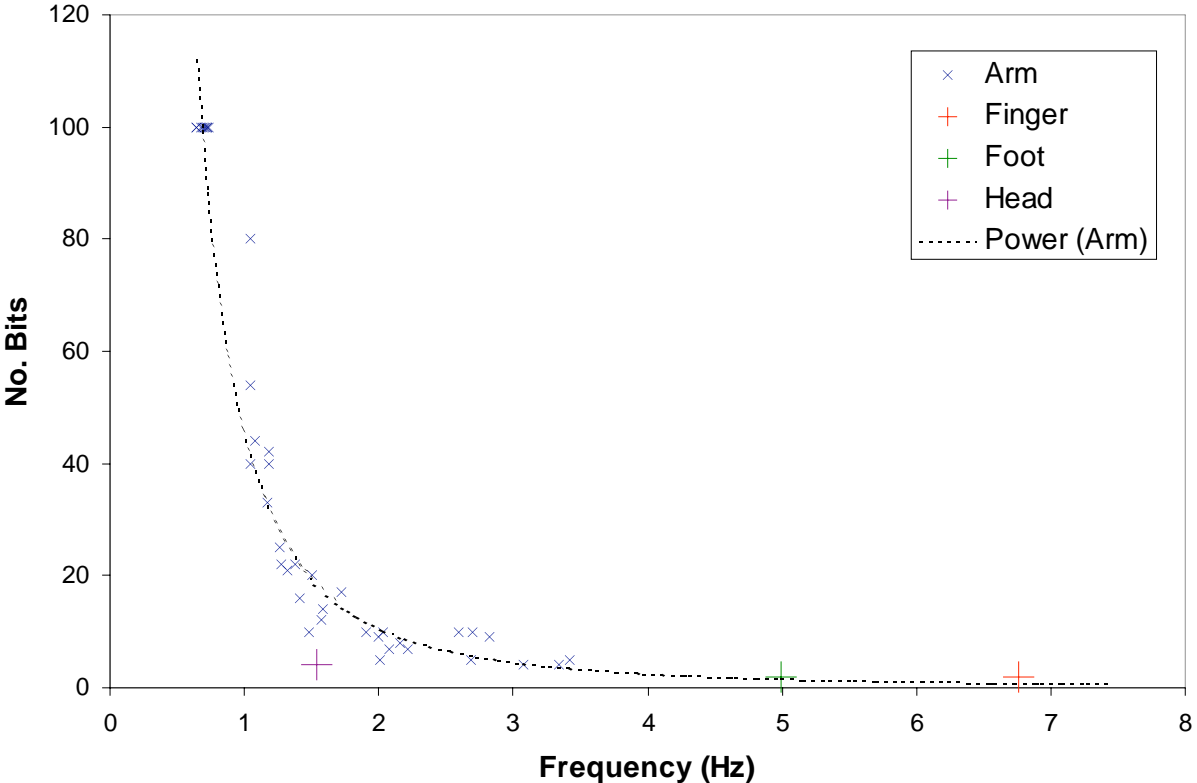


Figure 1: Frequency against bandwidth for various body parts.

Allowing for some small measurement errors, the points lie very close to the power law line predicted by Fitt’s Law: $MT = a + b \cdot \log_2(2A/W)$, where MT is the movement time, A is the distance between targets, W is the width of the target, and a and b are constants. As frequency of oscillation increases, the number of distinct bits that can be sent decreases. I will return to all data in this section and use it in comparison with that of Simon, Allan and Mali in part 3.

5.2 Consideration of musical instruments

To complement the approach of analysing my own body, I also gave some thought to the abilities of professional musicians. Using recordings of performances I thought demonstrated the abilities of the musicians well, I drew up table 3.

Instrument	Clarinet	Drum Kit	Piano	Trumpet	Violin
Full Range (semitones)	47	-	85	35	56
Useable Range (semitones)	30	-	49	29	30
Available Bits	30	10	49	29	30
Frequency in Recording (Hz)	8	15	17	12	11
Number of Actuators	10	4	10	4	4
Bits per Actuator	3.0	2.5	4.9	7.3	7.5
Frequency per Actuator (Hz)	0.8	3.8	1.7	3.0	2.8

Table 3: Frequency and bandwidth calculations for various instruments.

For the clarinet and the trumpet, the mouth is included as an actuator. This is because blowing harder or softer changes the pitch of the notes played. However, the bow is not included as an actuator for the violin, since it can be assumed that the fingers do the work of selecting pitch. The final two rows of table 3 place the instruments on the graph in figure 1, as shown in figure 2. The instrument data is largely supportive of the power-law relationship described above.

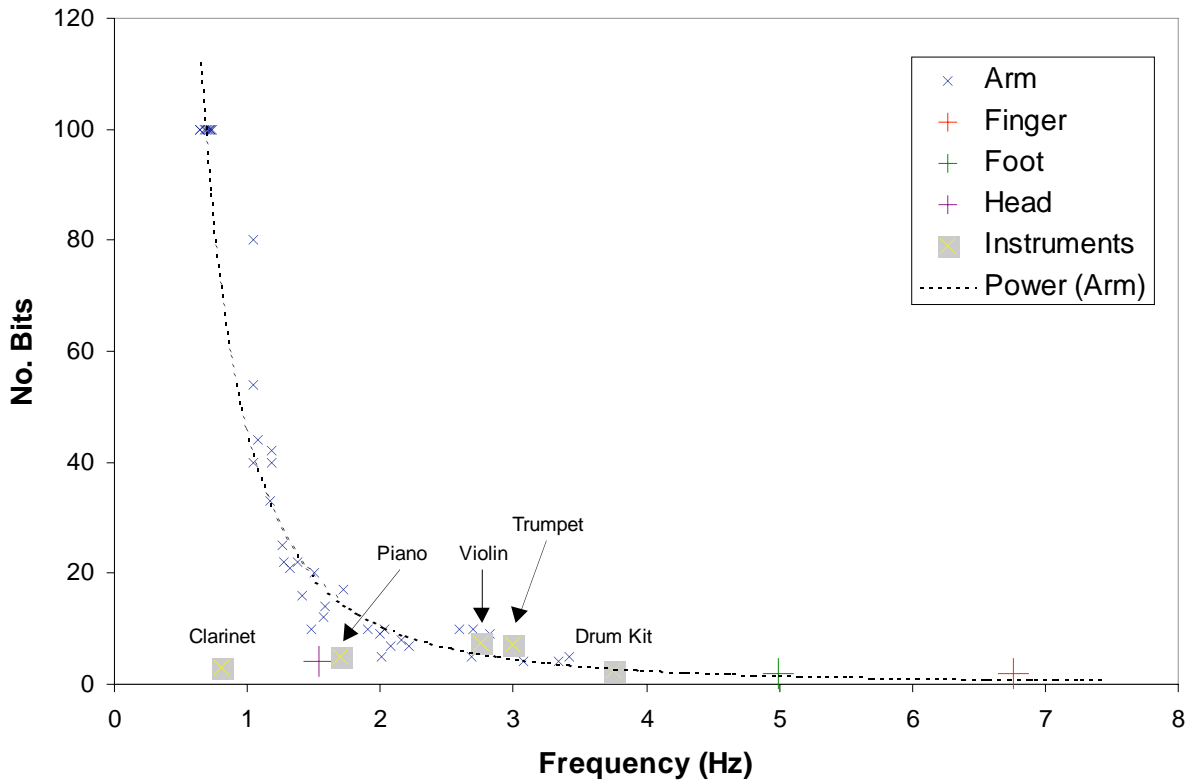


Figure 2: Frequency against bandwidth for body parts with instruments included.

5.3 Bioinformatics

Professor Wolpert of the Cambridge Department of Engineering is a specialist in motor neuroscience. I asked for his input regarding computer controllers for the disabled, and he directed me to a paper on postural hand synergies.²⁴ The paper describes a study of the interaction between the fingers of a hand as it grasps objects of different shapes. 57 common objects were used in the experiment, including an egg, a brick and a needle. As test subjects' hands moved to grasp these objects, the rotation, flexion and abduction angles of each of their fingers were carefully monitored. Once collected and analysed, the results revealed that two postural hand synergies are very common. These are known as the "precision grip" and the "power grip". The precision grip is that used to pick up a needle, an egg or a compact disc; the palm of the hand does not make contact with the object. The power grip is that used to grasp a wrench, an iron or a bucket; in this grip the palm of the hand does make contact with the object. Over 80% of all the results could be placed into one of these two categories. The implication for this project is that switches that make use of one of these two grasping positions will feel natural and easy to use.

²⁴ Marco Santello et al., "Postural Hand Synergies for Tool Use," *The Journal of Neuroscience* 18 (1998): 10105-10115.

6. Meetings

6.1 *The CUED Vision group, 11/10/05*

The Cambridge Engineering Department has a Computer Vision and Robotics group, which is led by Professor Roberto Cipolla. A PhD student in that group, Oliver Williams, has recently completed work on a piece of software which can recognise and track movements observed by a web cam. I visited the group on Tuesday 11th October to see a demonstration of the software.

The program can be set to respond to any visible motion. It works by taking an initial picture of what the camera can see. It then compares subsequent frames with this first snapshot and calculates the motion that has occurred, translating it into mouse pointer motion. This effective tool seemed to be perfect for Simon and Mali, because it would register whatever movements they could make, so I requested a copy of it.

The group kindly provided me with a copy of the software, but despite several people's efforts, we were sadly unable to make it work on my computer, and eventually had to use an alternative technology. The problem was probably due to a discrepancy between the settings on my machine and the one on which it was created, because it had not yet been made generally compatible. This is now being done by the Cambridge Inference group. It is to be made available for free download under the title of "the freevim project" and details are on the Inference group website.²⁵

6.2 *Philip Hughes, 9/11/05*

On Wednesday 9th November I met with an occupational therapist at Anglia Ruskin University. Philip Hughes spends a day of every week in a special needs school helping the children there communicate through music. His approach sounds very similar to Simon Gunton's: he uses simple instruments to encourage teamwork and gives each participant a turn at taking the limelight.

I asked him which instruments he finds most helpful in meeting his goal. Wind chimes are good, as well as the folk harp, which has ten strings in a scale. Both of these are simple to use, have a small range and provide exciting visual, haptic and auditory feedback.

²⁵ Details of the freevim project are at <http://www.inference.phy.cam.ac.uk/dasher/freevim/>

6.3 *The Rainbow Research Group, 16/11/05*

I met with three people from the Cambridge Computer Department's Rainbow Research Group.²⁶ The first two were Darren Edge and Lorisa Dubuc, on Wednesday 16th November. Darren is working on tangible user interfaces for computer control, and Lorisa works with people with dementia. They were able to suggest a number of controllers that might be ideal for Simon, Allan and Mali. These included touch pads, accelerometers to detect motion and orientation, seesaws, foot pedals and even sensors on the teeth. Lorisa stressed that computer controllers are made more accessible by increasing interaction and stimulation, so a strong use of colour is helpful.

6.4 *Dr. Blackwell, 25/11/05*

My second meeting at the Rainbow Research Group was with Dr. Alan Blackwell, on Friday 25th November. He had a lot of helpful input regarding user interfaces. In order to control a machine you have to think you know what it is doing, so interfaces should be as simple as possible. A good computer interface will be accessible to the novice, but also be powerful enough to satisfy the expert. The performer will not question how a program is converting head motion into sound, but merely wants to know what he should be doing with his head. Thus, the challenge is to make it clear what the user has to do. He pointed me in the direction of the cognitive dimensions of notations framework, which was initially conceived by Thomas Green.²⁷ The programmer should be thinking in terms of a notation that leaves the brain and is translated by the computer into a set of instructions.

Dr. Blackwell also described to me some work that was done to help people with tremors control a mouse more smoothly. The concept was that the computer took two inputs from the user: head motion and hand motion. The user directed the mouse pointer with both head and hand simultaneously, and the hope was that the tremors in the two signals would cancel out, leaving a smooth signal. I was interested in this concept in designing a system for Allan, but unfortunately the idea could not be made to work.

6.5 *Faustina Hwang, 22/1/06*

Faustina Hwang did her PhD on haptic feedback for computer control. I met with her on Sunday 22nd January to discuss how her work applied to my project. She worked extensively

²⁶ Web page for the Rainbow Research Group is at <http://www.cl.cam.ac.uk/Research/Rainbow/>

²⁷ Cognitive Dimensions of Notations resource site is at <http://www.cl.cam.ac.uk/~afb21/CognitiveDimensions/>

with disabled people in the course of her study and emphasised the importance of focussing on individual needs. Every case is different, so working with the people who need the technology is essential.

Her haptic feedback mouse has gravity wells around key features on the screen, so they become easier to select. She suggested that gravity tunnels on the screen might be a useful aid to selection in my case. Logitech now has a force-feedback mouse on the market, called “ifeel”. This was a good idea, but not the route I finally chose.

6.6 Professor MacKay, 24/1/06

On Tuesday 24th January I visited Professor David MacKay at the Cavendish Laboratory in Cambridge. Professor MacKay is the designer of an ingenious mouse-controlled word processor called Dasher, pictured in figure 3.²⁸ In Dasher, the typist moves the mouse to the right to increase speed, and up or down to select letters. With practice, typing at more than half the speed of a keyboard can be achieved.

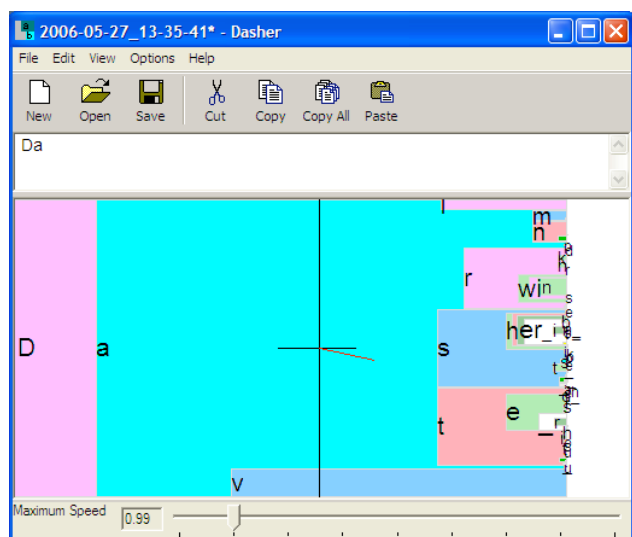


Figure 3: Screen shot of Dasher

Professor MacKay is an expert in information theory and computer interfaces for the disabled. He has already considered creating a version of Dasher that could play music, and we discussed how this might be done. However, since this is likely to be the subject of another report, I shall not include details on it here.

Professor MacKay kindly lent me a SmartNav (described in section 3.2) and some switches. He encouraged me to let Simon, Allan and Mali try out Dasher to see if they liked and could use it. It turned out that Simon and Mali could not (see section 7.4), but Allan got on well with it.

²⁸ Dasher may be downloaded free of charge. Visit <http://www.inference.phy.cam.ac.uk/dasher/>

7. Visits to Sue Ryder

7.1 First visit, 28/10/05

On Friday 28th October I visited the Sue Ryder Care centre in Ely for the first time. The purpose of the visit was simply to meet Simon, Allan and Mali, and it was also an opportunity to observe one of Simon Gunton's workshops there. He gathered about eight Sue Ryder residents in the common room, and the meeting proceeded much as it had at West Road. Some of the attendees, including Allan, were able to play simple percussion (such as bongos) well, but no one could really manage the xylophone. Simon could shake a tambourine, but only with a great deal of effort and some help from the Sue Ryder staff. Mali couldn't really contribute at all, but seemed to enjoy being part of the workshop.

7.2 Second visit, 29/11/05

The purpose of the second visit, on Tuesday 29th November, was to find a simple switch that Simon, Allan and Mali could use. In preparation for this visit, I designed five simple switches that made use of the two primary grasping positions described in section 5.3. These switches are shown in figure 4. Switches 1, 3 and 5 require the power grip, whilst switches 2 and 4 use the precision grip.

In order to ascertain how effective each switch was for each person, I ran the frequency and accuracy tests described in section 5.1. The results of these tests are discussed in section 8, but they revealed that switch 3 suited Simon best, whilst Allan preferred switch 1. Unfortunately, Mali was unable to use any of the switches.

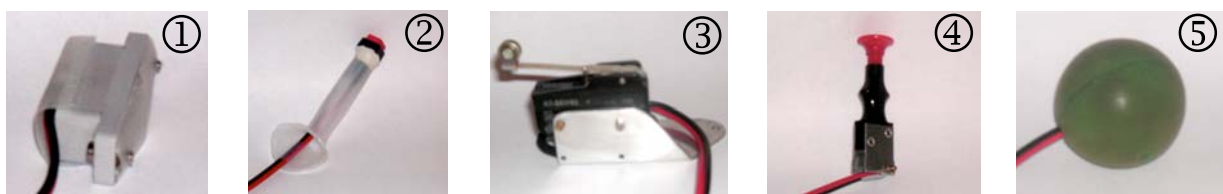


Figure 4: Photographs of the five switches.

In light of this testing, I continued the search for a switch that Mali could use. The results for the other two men were promising, but it was clear that a more sophisticated input device was

required in order to produce interesting music. At the time, I was unaware of the existence of SmartNav, and so opted for computer vision software.

7.3 Third Visit, 19/1/06

Throughout November and December I worked with the computer vision software described in section 6.1, but was unable to get it to work. My computer had trouble running the program, and none of the things I (or other people) tried could solve the problem. When January arrived I decided to redirect my efforts towards considering how to generate interesting sounds using only one or two simple switches.

I thought of three ways to do this: **layering**, **pre-programming**, and **notation**. These are all methods of increasing the complexity of the sound output in relation to the user input. The layering concept is that a complex thing can be created by putting a number of simple things together. The program I wrote to demonstrate this is shown in the top left quadrant of figure 5. Before starting it, the user has the option to set the tempo, the number of beats in a bar, and the number of bars before instrument change. (In this example program, a mouse and keyboard are required to do this). The program is started by pressing the space bar, and counts out an introductory bar at the stated tempo, before starting to record. The performer uses a single switch to record a rhythm on the first instrument (the bass drum) whilst it is highlighted in pink. Recording on the first instrument continues for the number of bars the user stipulated at the start, and then moves onto the second instrument (the snare drum) for the same number of bars. As soon as the pink highlight on the bass drum goes off and the blue highlight on the snare drum illuminates, the program stops recording the bass drum rhythm and instantly plays back the rhythm it recorded. It also simultaneously starts recording the snare drum rhythm, as inputted by the switch. This continues for all four parts of the drum kit (bass drum, snare drum, hi-hat, and crash cymbal) and then the cycle begins again. On the second and subsequent cycles, the performer can choose not to play anything, and the previous track will be repeated. If an input is received, however, then the previous track is erased and a new one recorded in its place. In this way it is possible to record a drum beat in four instruments in (almost) real time using only a single switch.

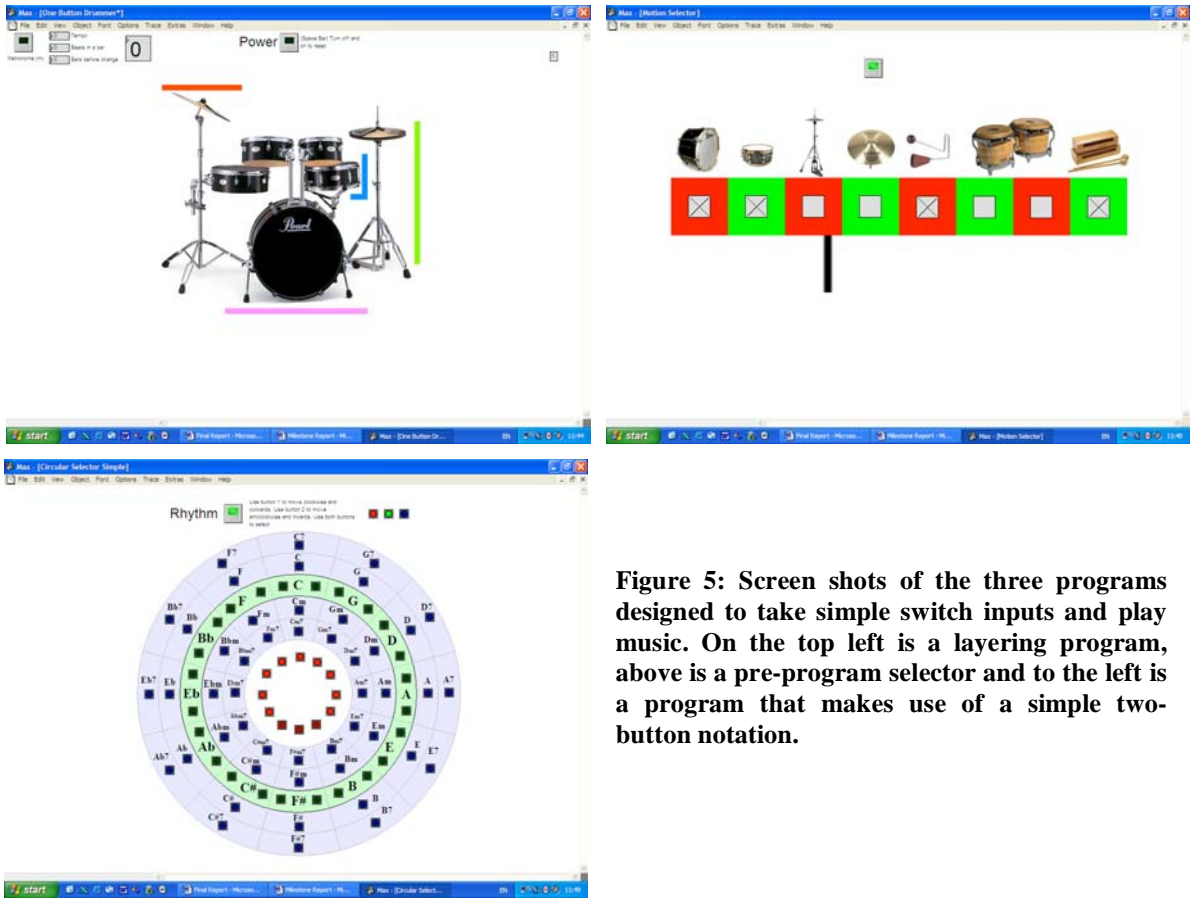


Figure 5: Screen shots of the three programs designed to take simple switch inputs and play music. On the top left is a layering program, above is a pre-program selector and to the left is a program that makes use of a simple two-button notation.

The program I wrote to demonstrate the selection of pre-composed material is shown in the top right quadrant of figure 5. The black slider in the middle of the shot oscillates between left and right, and clicking the switch when it is under one of the red or green boxes turns one of the instruments on or off. The eight percussion instruments each have a pre-composed rhythm attached to them, and so the role of the performer is simply to decide which sounds to include and which to leave out.

The program I wrote to demonstrate a simple two-button notation is shown in the bottom left quadrant of figure 5. It basically uses a menu system, not dissimilar to that used by E-Scape (the composition program in section 3.3). However, unlike most computer menus, none of the options are hidden, but all 48 (in blue) are laid out on the screen. All the green boxes represent the menu headings (chord names) and in the blue boxes are different types of chords in that key: major, minor, seventh, and minor seventh. The performer navigates around the selector using two simple switches (A and B); activating the two switches together creates a third input (C). There are two levels of selection. In the first level, the appropriate key is chosen: A moves clockwise, B moves anticlockwise, and C selects. In the second level the

chord is chosen: A moves radially outward, B moves radially inward, and C selects. Once a chord is chosen the system resets and begins again. Thus, any of the forty-eight states can be chosen in eleven clicks or fewer. The most efficient notation (based on binary numbers) could bring any of forty-eight states within six clicks. Thus, this system is not particularly efficient, although it is user friendly.

Although I had done my best to create interesting results with switches, my hopes of success were not high when I visited Sue Ryder on Thursday 19th January. Of the three programs, the layering and notation systems were hard to learn and would not produce immediate results. As I anticipated, neither of them was well received by Simon or Allan. However, both Simon and Allan enjoyed the pre-composed selector program (*top right in figure 5*), and Allan had excellent control over which instruments he turned on and off. When asked to turn all eight on, or turn off alternate instruments, his performance was almost perfect. However, as fun as this program might have been, it wasn't what Simon Gunton was looking for, so the conclusion was that I needed to try something else.

I had given some time to developing a switch that Mali could use, but neither of the designs I came up with were functional. I was told that others have tried to find a switch for him, but without success, so I abandoned the idea and hoped to get the computer vision software working.

7.4 Fourth Visit, 15/2/06

Five days after my attempt to make interesting music from simple switches, I had the excellent meeting with Professor MacKay at the Cavendish, described in section 6.6. Professor MacKay provided me with new ideas and new equipment, most notably a SmartNav unit, which uses infrared technology to enable control of a mouse pointer with the head. This opened up a wide range of options, and I began to design programs to test frequency and bit capacity in two dimensions.

On Wednesday 15th February, I returned to Sue Ryder to let Simon, Allan and Mali try out the SmartNav. I came prepared with a large number of programs, which needed various degrees of skill to use. The simplest one made a sound with a nod of the player's head. The most complex program had a 4x3 grid of boxes on the screen and would light one up at random. The user had to point to the highlighted box using his head, and click a switch, at which point

another box would light. I timed how many correct clicks occurred in twenty seconds. With practice, I could achieve 30.

Allan was first to try the SmartNav, using the reflective cap (*below*). He could nod his head up and down at a frequency of 1.65Hz, and shake it from side to side at 1.94Hz. He could click one of the switches at 4Hz, so his head was notably slower than his hand. This was consistent with the tests I performed on my own body, as shown in table 1 in section 5.1. Allan was able to control the mouse pointer well using SmartNav, and could reliably select between two, four and eight bits in two dimensions. When it came to running the “highlighted box” program for Allan, we made an interesting discovery. Allan struggled to get more than three correct hits with the SmartNav in twenty seconds, but then asked to try it with the mouse. With the mouse he could reliably achieve twelve hits. I had been informed that Allan could not use a computer mouse, and so had eliminated it as a possibility. When selecting large targets on screen, however, he much preferred it to the SmartNav. I was commissioned to design a program to make music with a mouse.



Afterwards, we let Mali try out the SmartNav. Unfortunately, he did not take to it, and we were not able to obtain any results from even the simplest programs. It became clear that he was not showing any enthusiasm for finding a solution, so Simon Gunton decided it was best that we did not pursue work with Mali any further.

Simon was unavailable on the 15th, so I went back to Sue Ryder two days later to let him try out the SmartNav. He clearly enjoyed the experience, and wanted to spend a lot of time playing a drum with his head. It became clear during the testing on the 17th that Simon was not making any connection between where the pointer was on the screen and the sounds being produced, but was making a direct link between head motion and sound. Thus, he was totally unable to use the switch to select things on the screen, but would probably be able to use it to alternate between two types of sound. This discovery was very instructive in the design process for Simon, and I went away to design a program that would take the input of pointer motion and play music with no reliance on visual feedback.

This concluded the tests at Sue Ryder, and provided all the information I required for design. The following section gives more technical detail on the test results, and the design process is described in detail in part 4.

8. Results of the Testing

8.1 Frequency

At least three frequency results were taken for each person on each switch he could use. The mean of these results is plotted on the graph in figure 6. The graph allows a direct comparison between the three switches for each person, and a comparison between hand and head frequency. I (Jon) achieved my highest frequency on switch 3, and can squeeze my hand at more than twice the rate at which I can move my head. Allan prefers switch 2, and his hands are only marginally faster than his head. The results for Simon are very intriguing; he can achieve higher frequency motion with his head than with his hands. His preferred switch is number 3, but he can nod his head more than twice as fast as he can click that switch. Another interesting feature of figure 6 is that Simon's head nodding is substantially faster than his head shaking. For Allan and me, it is only marginally faster. This should be taken into account when designing a program for Simon: such a program should make greater use of head nodding than head shaking.

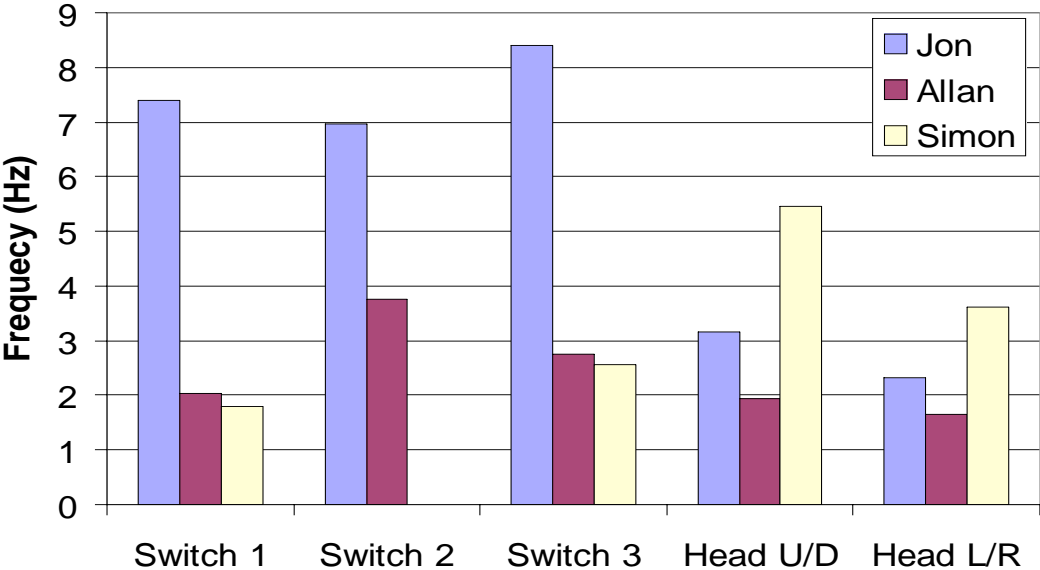


Figure 6: Frequency results for Jon, Allan and Simon using switches and the SmartNav

8.2 Accuracy

Figure 7 shows the results of the accuracy test for switches 1, 2 and 3.

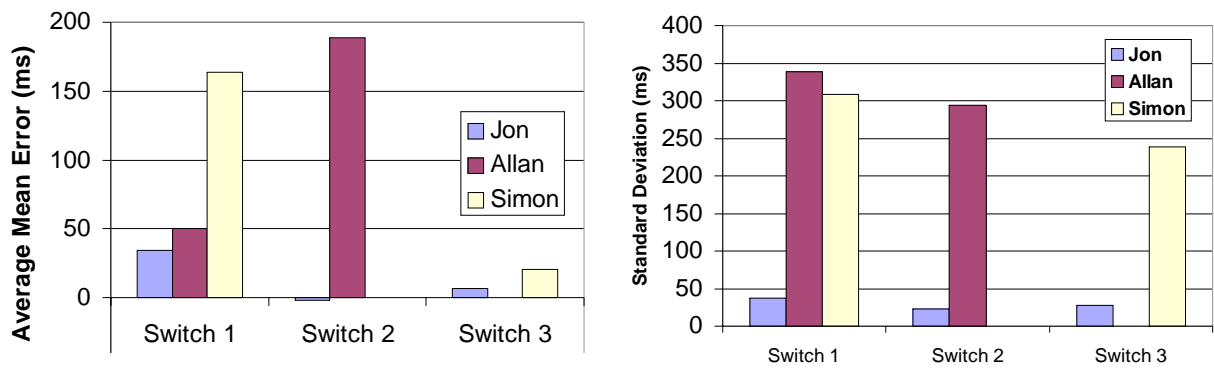
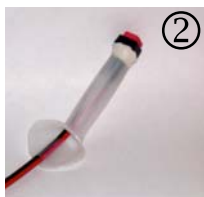


Figure 7: Accuracy results for switches 1, 2 and 3

The best measure of accuracy is the standard deviation, in which case Simon's best switch is 3, and Allan's is 2. Allan is consistently late with switch 2, but this is probably something that would improve with practice.

8.3 Switch choice



The results of the frequency and accuracy tests show that the best simple switch for Allan is switch 2 (*left*). He can operate this the fastest, and with greatest consistency. The best switch for Simon is switch 3 (*right*), although he can



achieve a higher frequency with his head. In his case the switch would best be used merely to alternate between two audibly different states, rather than as a mouse button.

9. Initial Ideas

9.1 Layouts of the notes of a scale

When it became likely that the main design focus of this project would be in computer interfaces, I gave some thought to ways of representing musical notes and chords graphically. A piano keyboard, or a xylophone, is effectively a one-dimensional note-selecting device, since the note pitch increases with key selection in the x-direction only. I considered that this might mean that interfaces that were one-dimensional were

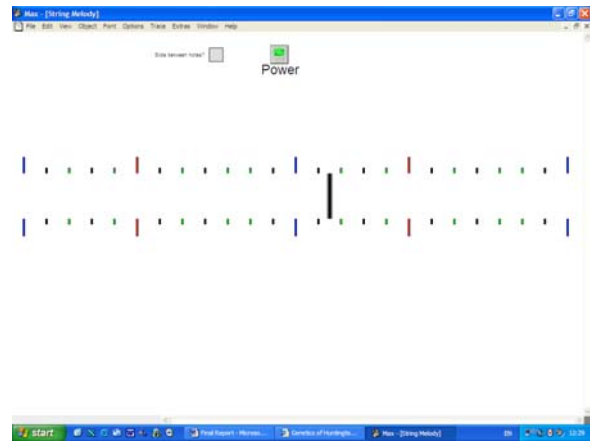


Figure 8: Example of a 1D interface

straightforward and natural to use, since we are used to this concept. Figure 8 illustrates a possible 1D interface. The black slider follows the mouse pointer, and the mouse button selects a note. Each of the small markings represents a semitone change in pitch, so this interface has a range of two octaves.

This interface produces a sound not unlike a swanee whistle, since it is difficult to select notes with a mouse that are not adjacent. In an attempt to improve the sound, I gave some thought to two-dimensional interfaces. These utilise both the degrees of freedom of a mouse pointer. I sought ways to assemble the notes of a scale in two dimensions in a way that made the most common and melodious combinations easiest to select. Two such interfaces appear in figures 10 and 11. The key to the various colours is given in figure 9.









Colour								
Note no.	1	2	3	4	5	6	7	8
(Name)	Tonic	Supertonic	Mediant	Subdominant	Dominant	Superdominant	Leading Tone	Tonic
Example	C	D	E	F	G	A	B	C

Figure 9: Colour coding of the notes of a scale

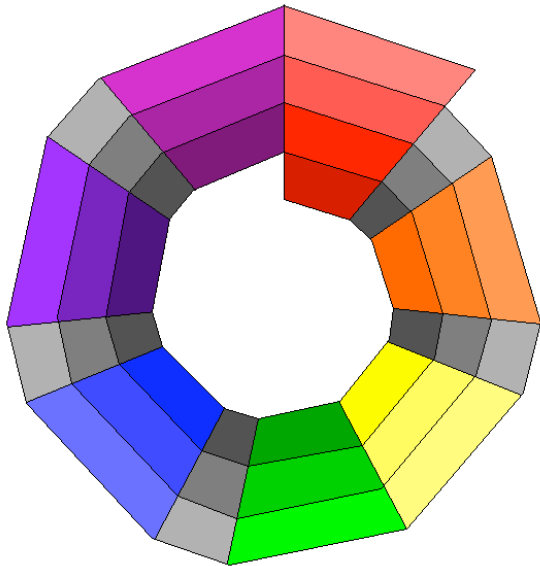


Figure 10: 2D interface A

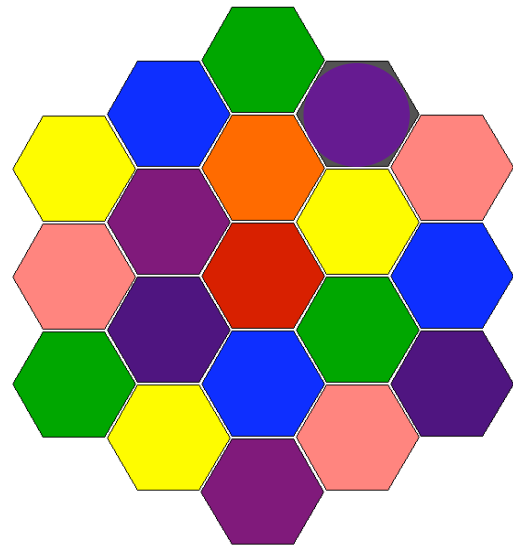


Figure 11: 2D interface B

In interface A (figure 10), the notes of the scale are arranged in a spiral pattern so that rotating clockwise increases the pitch by a semitone, and moving away from the centre increases the pitch by an octave. The range of this interface is three octaves (which is comparable to the range of most woodwind, brass and string instruments).

In interface B (figure 11), the notes of a single octave are arranged in a tessellated hexagonal pattern, and some of the notes are repeated. Unlike the first two interfaces, this one does not include any notes outside the scale (accidental notes, or black keys in the example key of C major). In designing this interface, I have tried to arrange the notes so that all the most common combinations are adjacent at some point on the grid. This is demonstrated in figure 12.

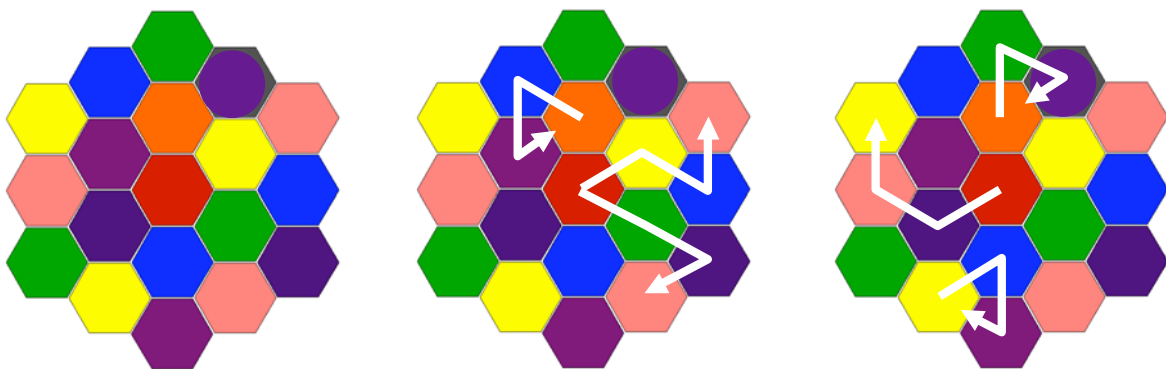


Figure 12: Paths on interface B that give (i) the major scale, (ii) the primary major triads, and (iii) the primary minor triads.

The range of interface B is only a single octave, which is a good deal smaller than most tuned instruments. However, its ease of use may compensate for this. As with the 1D example in figure 8, the notes are played by pressing the mouse button for both interfaces A and B.

9.2 *Layouts of chord patterns*

The interfaces above could potentially be used to simulate the majority of orchestral instruments: those on which one note is played at a time. However, for a small number of instruments, such as the guitar, accordion, and possibly the piano, it makes more sense to use the language of chords rather than individual notes.

There are a very large number of possible chords. For a start there are twelve major chords in every octave, and then for every major chord there is a minor chord, major seventh and minor seventh. This gives us 48 distinct chords per octave before we even venture into the realms of diminished and augmented chords, ninths, suspended chords and chords in the first or second inversion. Clearly the problem of arranging chords on a computer screen in patterns that make sense is much more complex than that for individual notes.

However, there are a number of ways in which this problem may be simplified. The first simplification is to take the guitar model of chord playing, and eliminate first and second inversions. Identical chords in different octaves may also be eliminated, as guitarists do not concern themselves with these. The next thing to do is to arrange the remaining chords in order of how commonly they are found in pieces of music, and then to decide on a cut-off point for inclusion or exclusion. The most common chord in any piece is almost always the tonic (C major in the example), closely followed by the major dominant and major subdominant (G and F). Pieces of music have been written that use nothing more than these three (e.g. some with a twelve bar blues structure). The next three most common chords are the relative minors of the first three: the minor superdominant, minor mediant and minor supertonic (Am, Em and Dm). With just these six chords, a surprising number of songs written in the twentieth century can be played.

Continuing this process, I discovered that the most user-friendly way to arrange chords is in a circle of fifths pattern, as in figure 13 below.

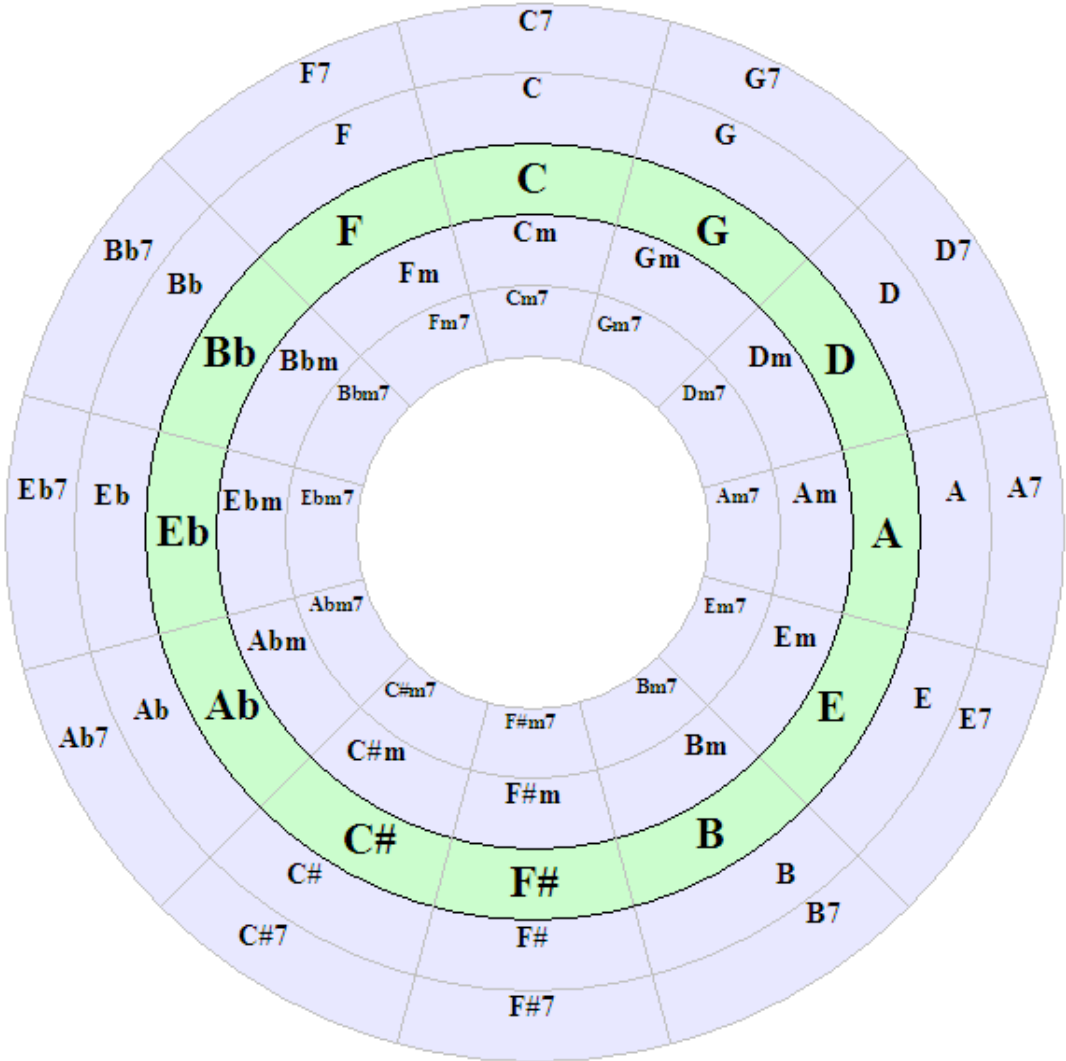


Figure 13: Circle of fifths arrangement of most common chords.

The arrangement in figure 13 contains all twelve of the different major chords in an octave, along with their minors and sevenths. Using the circle of fifths ordering means that the most common chords are all within half a circle of the tonic, C. The least common chord, F#, is furthest away from the tonic. When it comes to selecting chords from a chart, the arrangement in figure 13 is highly convenient.

10. Formal Design Process

10.1 Solution Neutral Problem Statement

Simon Gunton made it clear at the outset of this project that he was hoping to investigate electronic devices. Thus, the solution-neutral problem statement is as follows:

To design a computer-based system that will enable disabled people to generate sounds in a way that is creative, expressive, and compatible with the instruments currently used by Simon Gunton in his workshops.

10.2 Specification

The requirements of the prototype instrument are laid out in table 4:

SPECIFICATION	Requirement	Notes
Cost	< £100	
Weight	< 5kg	Easy to carry
Dimensions	< 0.3x0.3x0.6m	Fits easily into a car boot
Set-up/dismantle time	< 4 minutes	8 units in 30 minutes
Materials	Anything non-toxic	Also free from sharp edges
Ergonomics	Operable by the unskilled	

Table 4: Specification.

10.3 Evaluation of Alternatives

I have organised table 5 by musical decision in order of when it has to be made. It is not essential that a design provide for every musical decision on the list, so some variables are “pre-selected” (i.e. the programmer makes the decision and performer has no control over it at any stage). The other five control options are the ones that have been found to work for both Simon and Allan. The button click, button release, and 1D selection can only be used for one function, but 1D motion can be used for more than one if speed is taken into account. The “2D selection” option eliminates the availability of “1D motion” and “1D selection”, and vice versa. However, 2D selection can be used to control more than one variable if all but one are fixed before the start of the performance.

Instrument	Pre-selected	Button click	Button release	1D motion	1D selection	2D selection
Key	Pre-selected	Button click	Button release	1D motion	1D selection	2D selection
Pitch	Pre-selected	Button click	Button release	1D motion	1D selection	2D selection
Volume	Pre-selected	Button click	Button release	1D motion	1D selection	2D selection
Attack	Pre-selected	Button click	Button release	1D motion	1D selection	2D selection
Start Note	Pre-selected	Button click	Button release	1D motion	1D selection	2D selection
Alter Vol.	Pre-selected	Button click	Button release	1D motion	1D selection	2D selection
Vibrato	Pre-selected	Button click	Button release	1D motion	1D selection	2D selection
Tremolo	Pre-selected	Button click	Button release	1D motion	1D selection	2D selection
End Note	Pre-selected	Button click	Button release	1D motion	1D selection	2D selection
Portamento	Pre-selected	Button click	Button release	1D motion	1D selection	2D selection

Table 5: Evaluation of alternatives.

The red line in table 5 represents a design that might suit Simon. It does not rely on the use of a button whatsoever, but uses only motion. The design is unsophisticated, and does not offer the performer many choices, but this would make it simple and straightforward to use, which is ideal for Simon.

The green and blue lines in table 5 are design alternatives for Allan, who can use a mouse. In both options, he selects his instrument and key before commencing the performance. The blue line traces the less sophisticated route, offering the performer only four choices: pitch, when to start playing, when to stop playing, and whether or not to slur into the next note. A design like this is likely to provide instant results, but does not allow for much subtlety or creativity. Any of the interfaces described in section 9.1 could be used to embody this concept.

The green line in table 5 shows a design alternative that offers the performer control over every aspect of musical performance, except portamento. In order to achieve this, it makes use of the **motion** of the mouse pointer, rather than simply its position. The concept is that pitch is set by the x-axis position, and volume by the **speed** of motion in the y-direction, irrespective of direction. Thus, in theory, the attack of a note can be controlled by y-axis acceleration, the volume of the note can be increased or decreased as it is played by changing pointer speed, and vibrato can be controlled by altering the amplitude of the motion. The green route does

not utilise the mouse button at all (after the initial selection stage), which would make it a possible solution for Simon. However, the number of x-axis states he could select from would be limited. For Allan, the mouse button could be used as a shift key to add tremolo or portamento.

11. Final Designs

11.1 Simon

The concept traced by the red line in table 5 led to the development of the program in figure 14, called “Blue Frog”.

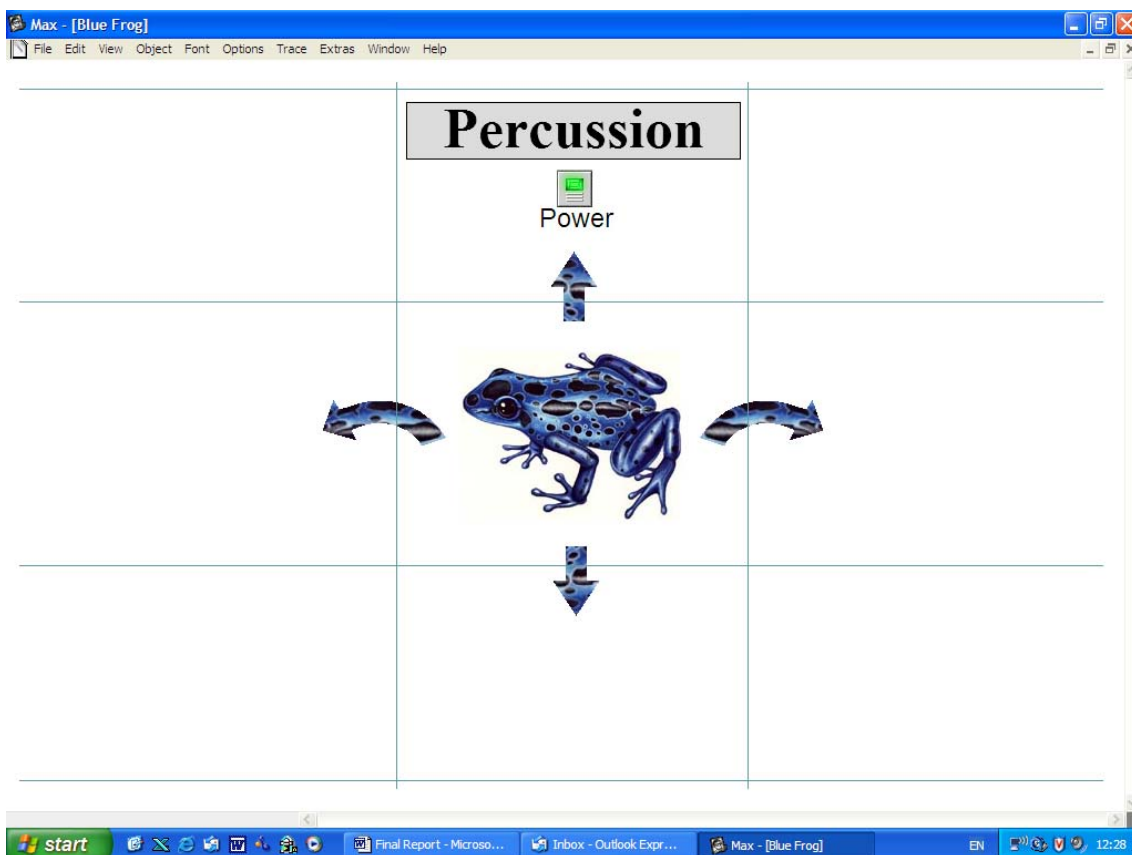


Figure 14: Blue Frog

For the embodiment design of the concept, I have deliberately kept the screen very simple. Using this program, Simon can play music without interacting with what is happening on the screen. Notes are played as he moves his head up and down. The screen is divided into five horizontal strips (the uppermost and lowermost are very narrow), and a note is sounded whenever the mouse pointer crosses from one to the next. Thus, four notes are sounded

between the top and bottom of the screen. The strips are not of even width, but have widths determined by a sine law, so that an even up-and-down head motion will create a regular rhythm. The screen is also divided into three vertical strips of even width. When Simon looks to the left or to the right, different sounds are generated. One final feature of the program – an addition to the concept in table 5 – is that Simon can change the instrument he plays. Three instruments have been programmed in: percussion, piano and bass guitar. He can cycle through them by clicking his switch.

11.2 Allan

The concept traced by the green line in table 5 led to the development of the program in figure 15, called “Colour Keys”.

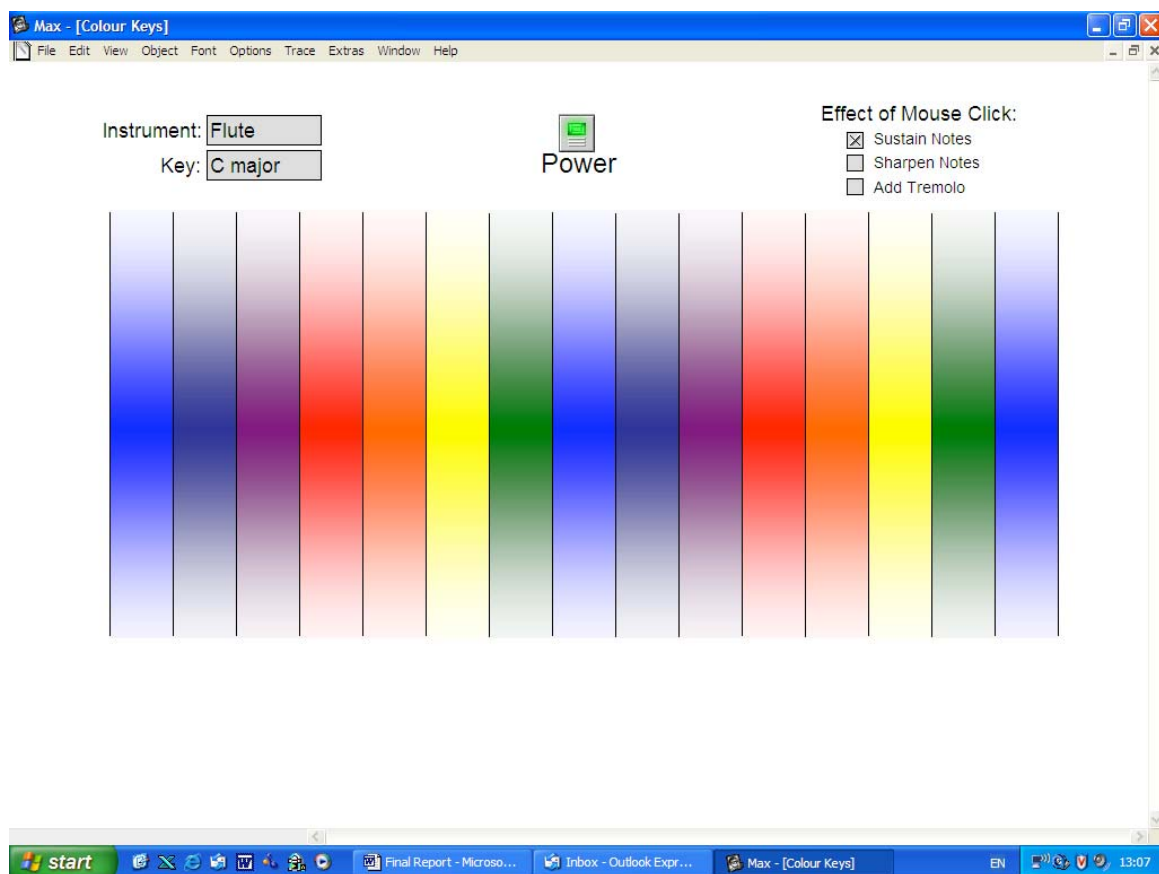


Figure 15: Colour Keys

In the embodiment design of this concept, the instrument and key are selected by the performer before beginning the performance from menus in the top left-hand corner of the screen. Each of the coloured bars on the screen represents a note of the scale, with the red bars being the tonics; this is a two-octave interface. A note is played by moving the mouse pointer

vertically over one of the coloured bars. The volume of the note increases with speed, as described in section 10.3. The program compares vertical speed with horizontal speed, and does not make a sound when the latter is greater. This means that non-adjacent notes can be selected cleanly without accidentally sounding intervening ones. It also allows for multiple soundings of the same note, by tracing a rectangle within the coloured bar. On top of this, the performer can choose what effect holding down the mouse button will have. “Sustain Notes” means that the sound output at the time of clicking the button is continued until the mouse button is released. This enhances the performer’s control over note attack, and allows for portamento. “Sharpen Notes” raises the pitch of the note played by a semitone, and “Add Tremolo” is self-explanatory.

This design is far more sophisticated than the one created for Simon, but should still provide instant musical results for Allan. It is powerful enough to give the performer creative choices, and requires only the input of a standard mouse.

11.3 Appraisal of Final Designs

The components required for both Simon’s and Allan’s instruments are a laptop computer, a mouse (\$10), an amplifier, cabling, and a copy of the Max/MSP software (\$495). Since the computer, amplifier and cabling were part of Simon’s original briefing, they need not be included in the part list. In addition, Simon’s instrument required a SmartNav unit, at an additional cost of \$300. This brings the total cost of his components to \$795, or approximately £425, which is too much. Fortunately, Escape Artists made contact with the two companies that sell the SmartNav (NaturalPoint) and Max/MSP (Cycling ’74). NaturalPoint provided Escape Artists with five free SmartNav units, and Cycling ’74 offered two lifetime leases for Max/MSP. These generous gifts have meant that the final cost of the prototypes is effectively nothing. Table 6 shows how the two prototypes compare to the original specification.

SPECIFICATION	Requirement	Simon's System	Allan's System
Cost	< £100	Free	Free
Weight	< 5kg	3.8kg*	3.5kg*
Dimensions	< 0.3x0.3x0.6m	0.2x0.3x0.4*	0.1x0.3x0.4*
Set-up/dismantle time	< 4 minutes	3 minutes	3 minutes
Materials	Anything non-toxic	Ok	Ok
Ergonomics	Operable by the unskilled	Yes	Yes

*These weights and dimensions include the laptop computer, as Simon Gunton would need more computers than he uses already, but not the amp, as he could just use one.

Table 6: Comparison of designs with original specification

Thus, both the instrument designed for Simon and that designed for Allan satisfy the initial design specification. It remains to be seen whether or not they will also fulfil Simon Gunton's requirements and allow creative musical expression in the context of his workshops.

12. Outcome

Working within Simon Gunton's initial specifications, I have investigated the best way for a disabled person to make music with a computer. I have researched all the commercially available computer input devices, and have analysed the potential in each. I am confident that there are no better technologies available in our price range than the ones chosen. I have sought to use these input devices to optimum effect in enabling musical creativity, and have designed a program that gives the performer almost as many choices as a traditional musician. The two final instrument designs meet all the technical requirements made of them, and should also satisfy Simon Gunton's expectations for the project, as described in section 2.3.

My role as part of the Escape Artists team is officially over, but my involvement will continue for a few more weeks. Simon Gunton has scheduled a concert for his orchestra at the Royal Opera House in London on Sunday 2nd July. He has expressed the desire that Simon and Allan take part in this concert on the instruments that I have designed, so I anticipate a few more visits to Sue Ryder.

13. Opportunities for Further Work

My year's work in music access for the disabled has revealed what an enormous field it is. This study has been very specifically centred around three individuals, but even with such a narrow focus there are many opportunities for further work. I have divided these into the areas of control, feedback, sound quality, making music, and musical intelligence.

Control:

- Further work is needed to find a controller that Mali can use. Computer Vision is the most promising possibility – he has good eye and blinking movement.
- A number of controllers were eliminated from the running due to high cost. With more money, exploration of the potential of Soundbeam and the EEG cap could be fruitful. The latter is already being investigated for use with a MIDI keyboard by Eduardo Miranda of UNESCO.²⁹

²⁹ UNESCO is the United Nations Educational, Scientific and Cultural Organisation: <http://portal.unesco.org>

- This project has not dealt with specialist controller designs, such as seesaws, arrangement of objects, rolling balls or accelerometers. Some of these might yield better results than I have had with switches and head trackers.

Feedback:

- Perry Cook and Sergi Jordà have demonstrated the importance of auditory, haptic and visual feedback. I gave thought to these areas in my design, but in the end had to prioritise other considerations. Further study is needed in this area.

Sound Quality:

- All the work for Simon, Allan and Mali has used simple MIDI instrument sounds. These are easy to use, but of relatively low quality. Research into better electronic instrument sounds is going on across the globe, but making them sound as good as traditional instruments remains a difficult problem. Using instruments which only produce poor quality sounds is going to diminish the performer's desire to play them, so this would be a profitable investment of time for future projects.

Making Music:

- In this project I have developed electronic instruments that mimic the traditional instruments that Simon Gunton already uses in his workshops. My designs are for one performer to play one note or beat at a time. However, there is vast creative scope if one can depart from this paradigm. Multiple-user interfaces, which take inputs from many performers and create a complex sound, have been already developed by Sergi Jordà and others. These have great potential for assisting communication and generating exciting music.
- In some ways I have not played to the strengths of computer technology in trying to mimic traditional instruments. There is a great deal that computers can do with sound that instruments cannot, such as layering sound waves on top of one another in a controlled way. Systems for the disabled that make music in a totally different way to the way traditional instruments do could be very exciting.

Musical Intelligence:

- David Cope at the University of California has written on musical intelligence.³⁰ He has trained a computer to recognise the compositional patterns of famous composers and to write music in their styles. This idea could potentially be extended to performance, if a system not unlike Dasher (section 6.6) could be devised. Such a program would predict the most likely course of the music and make it most accessible to the performer.

This project achieved what Simon Gunton required, but has only begun to cover all that could be done in this field.

³⁰ David Cope's homepage is at <http://arts.ucsc.edu/faculty/cope/>

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