Chapter 12.

Shaped, Embroidered Musical Instruments

As Musical Instruments

The final *Shaped Embroidered Musical Instruments* presented in this thesis, demonstrate how multifunctional and smart materials can dramatically improve the design and process of creating computational objects. In these instruments, sensors, wires and housing are all replaced with the single, durable and flexible material, smart textiles. These instruments also demonstrate how physical objects might become less neutral, and how the form and tactile properties of an object might reflect, and directly interact with computation or software. Each instrument has an overall shape and design that is appropriate to its software, and that directly influences its musical output. The careful placement of ground electrodes allows for an immediate playing style that emphasizes

Figure 12.1 *Shaped Embroidered Musical Instruments.*

natural squeezing. This gesture of squeezing is often reflected in the music that the instrument creates. The sensor size and placement relates closely to the musical functionality of the instrument. These instruments also represent a real advance in the development of *functional ornament*. The visual design of each sensor electrode is directly related to its electronic, technical and instrumental needs. Finally, these instruments are physical computing objects and musical instruments that are truly *materially antithetical* to normal musical instruments and computing technology. And these soft and squishy objects use fabric, normally an acoustic and electrical insulator, to conduct electricity and make music.

Music Shapers* in Tod Machover's *Toy Symphony

All of the *Shaped Embroidered Musical Instruments* are designed to be part of a larger project called the *Toy Symphony*. The goal of this project is to introduce kids to musical creativity in a new way. Music Toys are one of the main tools for this. Ultimately, these instruments/music toys will be used for both music workshops involving kids and mentors, and performances with kids and a symphony orchestra on stage. According to Machover:

> "Toy Symphony is a three-year project (1999-2002) to combine children, virtuosic soloists, composers, and symphony orchestras around the world to radically alter how children are introduce to music, as well as to redefine the relationship between professional musicians and young people. A complete set of Music Toys will be distributed to children in each host city (including New York, Boston, Manchester/London, Berlin and Tokyo),

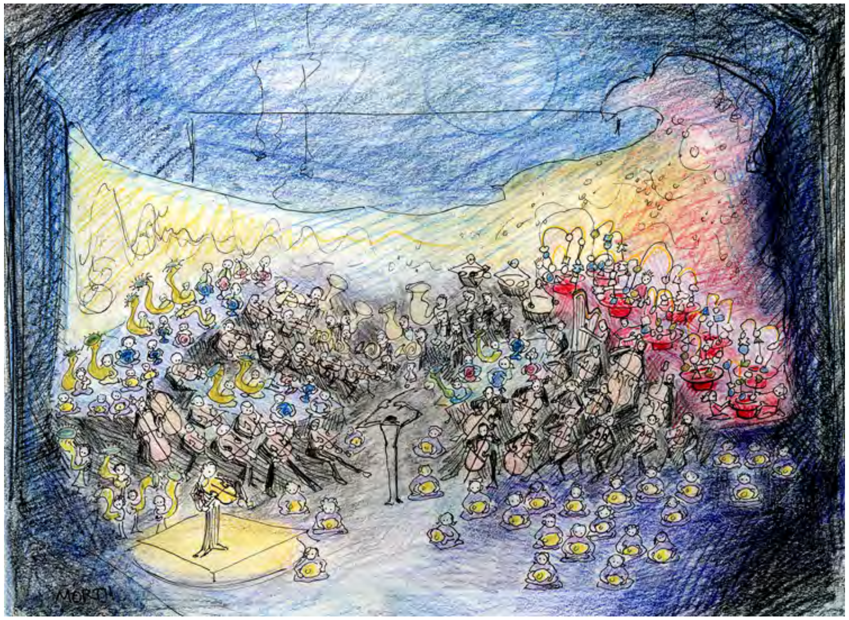

Figure 12.2 Conceptual illustration of kids, soloist and orchestra on stage in the *Toy Symphony*, Maggie Orth, 2000.

where children will be mentored to create their own sounds and compositions for toys and traditional instruments. A pedagogy for using these Music Toys to teach - and instill a love for - musical creativity will also be developed. Final concerts will be presented in each host city including kids' compositions and especially commissioned works by young composers, to be performed by children, soloists, and orchestra, playing Music Toys, Hyperinstruments, and traditional instruments."[1]

To accomplish all this, the *Embroidered Musical Instruments* must be durable, reproducible in at least a limited number, and ergonomic (physically able to be picked up, and played relatively easily by kids). So while I may have many abstract artistic and design goals for these instruments, they are also highly practical. They can be manufactured at a normal commercial embroidery house. They are durable. They are also relatively ergonomic, and designed to be playable by the small hands of children.

Within the *Toy Symphony*, these instruments are part of a larger instrument category called *Music Shapers*. These instruments are intended to let kids *shape* existing music at a relatively high level of expressive function, rather than at the level of note-by-note control. For instance, each of these instruments control three different pieces; the *Sound Sculpture Pyramid* allows for the mixing of audio filters and timbral exploration, the *Melody Tube and Butterfly* allow for the distinct control of two melody lines, and the *Big Ring* lets

[1] Machover, T., Opera of the Future Website, http://www.media.mit.edu/hyperins/projects.html#TOYSYM, World Wide Web, (2001).

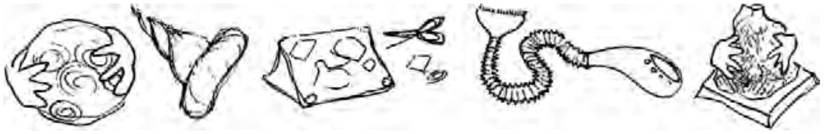

Figure 12.3 Conceptual sketches of Music Toys, including, *Embroidered Musical Ball*, musical costumes, musical collage, sonic vacuum, and musical clay, *Toy Symphony*, Maggie Orth, 2000.

players re-mix only a few lines of music from a large and potentially cacophonous set of pre-composed musical lines.

Squeeziness and Shapability

The squeeziness of the *Embroidered Musical Instruments* is metaphorically linked to the idea of *shaping*. Ideally, we thought of *Music Shapers* as made from a sort of musical clay, like clay on the potter's wheel that the computer could sense. One prototype of such musical clay was Josh Stirckon's *Musical Play-doh*. [2] *Musical Play-doh* used a platform of four electrodes to make pair wise measurements of the resistance in the salty and conductive Play-Doh that sat on top. While this sensing method did provide some clear idea of the movement or mass of the Play-doh on top of the electrodes, it did not provide an image of the clay's shape. I found this to be conceptually misleading. Kids and people would want to shape the clay into animals and houses, but we could not really see that. We could not even see if the shape of the clay was square or round. Moreover, it is totally unclear how to translate such shapes into music. This might not be a problem for an individual work of art, where an artist establishes a "personal" relationship between certain shapes and music, much like we did in the linking sounds to images in the *Digital Veil*. But an instrument needs some greater internal logic that transcends such highly subjective image/musical associations.

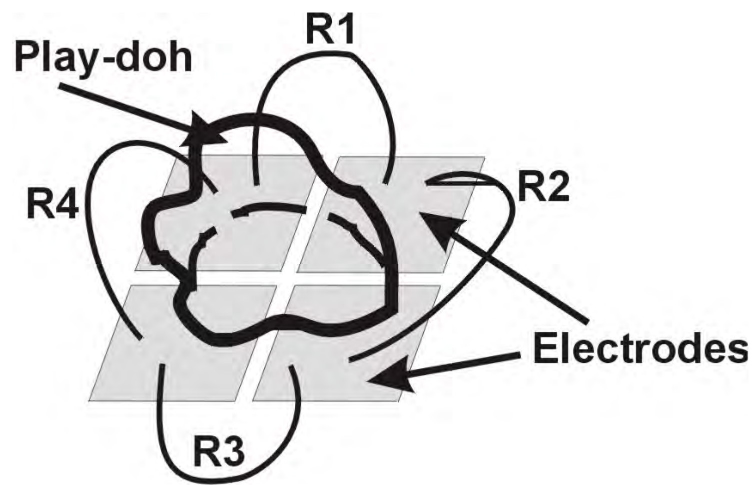

Figure 12.4 Diagram of Josh Strickon's *Musical Play-doh.*

[2] Toy Symphony Website, http://www.media.mit.edu/hyperins/toysym/phaseiframes.html, World Wide Web, (2001).

For both these reasons, (the technical inability to actually "see" the shape of the clay, and the "subjectiveness" of the linking of realistic images to music), I found the idea of relating the literal physical shape of a piece of clay to music highly problematic. The intention of the *Music Shapers* is to let kids shape *music,* not make a sculpture. Consequently, the *Shaped Embroidered Instruments* are not a sculptural medium for creating a shape. In fact, it is important that these shapeable *instruments* are not confused with a *sculptural and shapeable material* as a laid out in the supporting arguments of this thesis. As wholly formed fabric instruments the *Embroidered Instruments* do not set up any expectation that they are a sculptural medium that can be made into a specific shape and then imaged. Instead, their squeeziness lets kids use the *process* or *act* of shaping, to shape and form music. In this way, the *Embroidered Musical Instruments* are objects whose tactile squeeziness is a metaphor for the actual shaping they do of music.

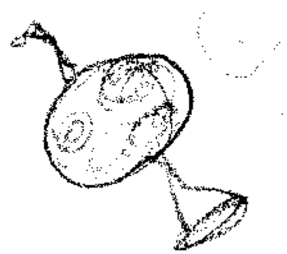

Figure 12.5 Sketch of Ball-horn, in which the speaker is a hard, plastic horn in the center of the embroidered ball, Maggie Orth, 2000.

In many ways, preserving the softeness, squeeziness, and metaphorical shapability of these instruments has been my foremost design goal. In fact, my greatest satisfaction is when the music these instruments create, sounds "squeezed". (This happens most often in the *Sound Sculpture Pyramid*.) This is a confession, because emphasizing squeeziness has meant making many design trade-offs, and sometimes musical ones. Except for the small circuit board located in the center of each instrument, I eliminated every other technological material that might interfere with the softness of these instruments. Speakers are off-board, and no hard lights are used for visual feedback. This means the sound does not come from the instrument itself, and that for visual feedback a player must look at a computer screen rather than the instrument itself. Finally, keeping the *Embroidered Musical Instruments* squeezy and soft, has meant that all their sensors are continuous and that these instruments lack any discrete input. When we tested the *Pyramid* running both timbral and melody software with Mattel[3], this was a clear problem. Kids wanted to touch something and hear something *immediately*. But in the *Embroidered Musical Instruments*, the sensors start at zero and progress upwards, gradually turning musical parameters on. This meant that even though the sensors might see a touch, kids might not immediately here any music, until the sensing info got high enough to trigger a music event. A one-to-one mapping of some discrete sensor to a musical note might help these instruments immensely.

Quick Demo, Commercial Toy or Practiced Instrument?

One of the challenges of designing these instruments, both in software and hardware, has been balancing ease and immediacy of play, with depth of musical experience. While here in the Media Lab, these instruments had to be a good "demo", i.e., create an immediate and satisfying musical experience for an adult visitor who might only spend 30 seconds playing one. For the *Toy Symphony*, the *Embroidered Musical Instruments* had to be physically and musically far easier to learn and use than a violin, able to be

[3] Cambridge, MA, boys and girls ages 6-11, (September 30, 2000).

Figure 12. 6 Still of video from Mattel toy testing with nine year old girls, September 30, 2000.

practiced and learned in short, (1 week) workshops, and also provide the player with a real sense of control and meaningful musical experience. For an event like the Mattel Toy testing, (in which Mattel was trying to determine if music toys could become commercial products), the kids had to be able to pick one up and get a cool musical response, and then feel that they would play with the instrument over an over again. Trying to create an instrument that is easy to play, repeatable, provides an immediate and satisfying musical response, is commercially viable, musically meaningful or sophisticated, and provides the player with the ability to learn and improve is no easy task, in either software or hardware.

In software, high-level musical control of pre-composed music or higher-level parameters, like volume and melody shape, can provide immediate musical success and allow for the exploration of expressiveness and creativity in children. But balancing immediate musical satisfaction with something that has musical depth is difficult. According to Weinberg:

> “My challenge as a designer of such digital musical instruments for children will be to balance between these two opposite approaches by providing a rich and expressive musical experience that can also allow for low-level manipulation. The instruments that I design should allow for players to smoothly transit between these two ends, taking into consideration that extreme high-level control might not allow for

precise exploration, while extreme low-level control might impair expressive and fun aspects."[4]

(Gili Weinberg gives such an eloquent description of this problem that rather than paraphrase it, I have included in Figure 12.7)

The physical design of digital musical instruments presents a similar challenge and Weinberg eludes to it in his thesis. Traditional instruments like a cello can take years to master *physically.* This can be overcome with software mapping, *or* with physical design. Software can compensate for an incorrectly timed or played note. But it cannot compensate for needed to learn how to hold the violin or the bow. It is possible to design physical instruments that can be immediately picked up with no instruction, and played with everyday gestures, (like squeezing), and that can take no time to practice or learn. This requires making the sensors highly sensitive and the first thing your hand touches. In the case of the *Shaped Instruments*, this meant making sure that anytime a player held an instrument, his or her hand was in contact with ground and a sensor. For kids, it meant calibrating the sensors to be very reactive to their small bodies and hands. But making instruments physically immediate can have high trade-offs. Recalibrating sensors led to far less degrees of control on the sensor. The physical design, that lets players use natural squeezing gestures to play music, also means that players have less precise one to one

[4] Weinberg, G., Expressive Digital Musical Instruments For Children, Thesis for the Degree of Masters of Science of Media Arts and Sciences at the Massachusetts Institute of Technology, Cambridge, MA, (1999).

"One of the premises for the new digital musical instruments' design is that there are intermediate levels of involvement on the axis whose ends are playing the cello and pushing the Play button. By combining discursive low-level controllers with presentational higher-level ones, new musical experiences, which are based on an interaction between these complementary levels of representation, can emerge. These interactions can offer expressive and creative musical experiences without requiring an exhausting learning process, virtuosi performance skills or an extensive body of musical theory knowledge.

They can also bridge the gap between different symbolic systems and address bricoleurs as well as planners, figuarlists as well as formalists. Performance skills and music theory proficiency are usually required in order to master the control of low-level musical building blocks, from single notes to melodies, harmony to articulation. In a traditional music learning process, however, these low-level musical aspects often block the vision of expressiveness, creativity and fun that fortunate professional musicians can experience after a long perfection process. The digital musical instruments' design suggests the use of additional, higher-level, musical controllers as intuitive and expressive intermediate involvement tools. These controllers can be helpful for a more immediate introduction of young potential musicians to the fun aspects of playing music, while still allowing for a rich and meaningful musical interaction. An example for such high-level musical control would be the manipulation of musical "stability" [Dibben 1999].

Digital musical instruments can allow children to interact with such a high-level concept by providing an algorithm that controls interval range, rhythmical consistency, fluctuations in timbre, etc. Another, more generic, intra-cultural example would be the manipulation of melody contour. Psycho-acoustic studies show that two melodies in different scales which share the same articulation, tempo and contour (but not the same pitches) can be perceived as very similar to each other [Schmuckler 1999].

Some experiments show that subjects found such pairs of melodies even more similar to each other than the very same melody played twice with different articulation or tempo. This phenomenon suggests that melody contour can serve as an intuitive high-level control, where users are not generating specific notes, but continuously controlling the abstract "height" of the melody line, based on a pre-programmed scale. It is important to remember, however, that a deep musical experience should also provide low-level delicate control and accurate manipulation of lower-level musical building blocks. Without these features, the high-level musical experience might lead to vagueness and confusion, which can impede further exploration. A comprehensive control of fundamental musical components (such as accurate pitch, velocity and timing) can motivate players to meticulously construct higher-level musical structures. Being provided with only vague high-level control might discourage such players who prefer delicate, precise and controllable manipulation."

Figure 12.7 Weinberg, G., Expressive Digital Musical Instruments For Children, Thesis for the Degree of Masters of Science of Media Arts and Sciences at the Massachusetts Institute of Technology, Cambridge, MA, (1999).

control over specific sensors. Moreover, the sensing technique used in these instruments (complex/impedance sensing or “intimacy sensing), proved far more technically appropriate for instruments designed for immediate and expressive response vs. one-to-on control.

A Natural Squeezing Style and Intimacy Sensing

The sensing method used in the *Embroidered Instruments* is essentially a measurement of skin impedance,[5] or what I came to call *intimacy sensing*. This technique has very particular physical design requirements and is also extremely sensitive to external factors that change a player’s skin impedance, like hand washing and even temperature. Over time it became clear that because of the physical design constraints and artifacts of skin impedance, this sensing technique was most successful when instrument design emphasized a *natural squeezing style* that used the whole hand to control multiple sensors, rather than *finger-by-finger* control of individual sensors.

During the development of the *Early Embroidered Musical Instruments*, I had empirically observed many factors about the sensing technique that led me to artistically describe this sensing method as *intimacy sensing.*[6] I observed that the more physically intimate, i.e. the closer, and longer a person’s hands were in contact with the sensor and ground electrodes, the

[5] See Chapter 14, Complex Impedance Sensing.
[6] See Chapter 13, Complex Impedance Sensing.

more reliable and reactive the sensing was. Consequently, while pressure from squeezing contributed to the reaction rate of the sensor, it was not the only factor. How long a person was holding the ball also made the sensors more reactive. The area of a player's hand on the electrode made them more reactive. How well the person was grounded also made them more reactive. These observations had specific design ramifications. In general, electrode design needed to emphasize high conductivity, a wide area and significant density of conductors on the surface for direct contact with the skin. The placement of electrodes had to allow players to easily grab the ball, squeeze it and get a good contact with both sensor and ground electrodes. All these technical requirements are strongly reflected in the design of the final instruments.

A natural squeezing style works far better than finger-by-finger control. Squeezing with the whole hand gives players simultaneously a good contact to both ground and sensor electrodes. It also lets players use various parts of their hands. This is important because the skin impedance of the player's hands contributes to their ability to control the sensors, and different parts of the hands have different levels of impedance. Consequently, it would not be unusual for one player's pinky to work well and another's to work badly. In addition, I have noticed that using individual fingers to control specific sensors requires a light touch. Thus, the palm, (if finger-by-finger control is used, this is the musically inactive part of the hand), which must touch the ground electrode, may not have enough "opposing" force to be very good electrical contact with it. The most successful instrument designs let people trigger sensors by using natural squeezing gesture and create opposing forces in either a single hand or between two hands.

It is important to note that while the natural squeezing style emphasized by the physical design of these instruments does reflect the musical goal of using everyday gestures for musical expressivity, it also relates to the fundamental limitations of the sensing technique. The *Embroidered Musical Instruments* do not always provide an ideal level of precise control. Gili Weinberg must be credited with doing a marvelous job of creating software was that was very forgiving of the artifacts and limitations of skin impedance sensing.

As Sculpted Computational Objects

A Relationship Between Physical Form and Music Software

The specific design of the *Shaped Embroidered Instruments* clearly transcends neutral physical computing objects, like music controllers that can be mapped to any piece of music software, or neutral computer mice. This is because the shape and sensor design of each instrument is *necessary* and specific to the composition and type of music it performs. For this reason, I have come to think of these instruments as being *physically composed*. I first heard the expression “composed instrument” in a talk by Dan Truman.[7] He referred to his built instruments, like the BOSSA[8], as *composed* because the software he wrote determined what music he could play, and was *part* of the piece he was performing. The idea of performing composed music is, in fact, something that the Hyperinstruments group has been doing for years. After his talk, I realized that my physical instruments were in fact, *physically* composed. Rather than being neutral, or good for playing many different pieces of music, these instruments are physically designed to facilitate very particular types of music or musical compositions. They do this by physically setting up very specific relationships between sensors, the players hands, and consequently the musical parameters they explore.

If we think of pre-composed music software running inside an instrument as determining or limiting some of the choices that a performer can make, we can also think of the physical relationship of sensors as determining or limiting choices. Thus, instruments like the *Pyramid* that force physical sensor interdependency, or make players touch multiple sensors at one time, are not suited towards a musical application that needs one-to-one control. These instruments are however, ideal for applications where the point is to combine parameters, or where no sound is made if only one parameter is played. (For instance a sensor mapped only to volume, might create no sound

[7] Truman, D., Reinventing the Violin, Thesis for the Degree of Doctor of Philosophy at Princeton University, Princeton, New Jersey, (2000).
[8] See Chapter 5, Related Work.

if it is not played with a pitch sensor.) Moreover, the physical placement and relationship of sensors on instruments can both encourage certain combinations of musical parameters and prevent them. In fact, Gili Weinberg managed to turn the ability of these instruments to limit choices into a feature in the *Big Ring*. For this instrument, he wrote a piece that would be cacophonous if the player could trigger all the sensors at once. Thus, by limiting the number of musical lines a player can trigger simultaneously, the physical design of the instrument helps and guides the player in performing the piece.

A Hands-on Design Process

My ability to create a relationship between physical form and music software is ultimately a reflection of the direct process by which these instruments were designed. This process was a hands-on investigation with *real* materials (the final materials of the object, not mock-up materials or models) that led to new ideas and artistic choices that we simply could not have made or imagined without the *actual* experience of the physical instruments, materials and software. Each instrument went through numerous iterations in both physical form and software. Because some instruments were completed before others, this process often included the pairing of instruments with the *wrong* music software, (software that was not conceived originally for that instrument). The pairing of oddball software with instruments led to an iterative design process that allowed us to closely look at how different physical designs interacted with different types of music software. Sometimes the musical application came first,

Figure 12.8 Early mock-ups for the *Pyramid* included a stuffed prototype with drawn sensors, and a variety of sensor and ground electrode designs.

guiding the physical design of the instrument. At other times, the application was actually built around the features or even bugs of the physical design of an instrument. In addition, features of some instruments were added to others based on the playing of different applications with different instruments. In this way, a real back and forth between instrument design and music software emerged.

The ability to directly shape and form the fabric also allowed me to easily experiment and iterate with different physical forms. The smart textiles let me simultaneously experiment with the shape and size of the instruments, refine the electrical, tactile and visual components of the individual sensors, and design the overall placement of the sensors and ground electrodes. The typical process for instrument design involved first conceiving of an appropriate shape, mocking up a stuffed, non-electronic model, trying it for size and general sensor placement, and then changing it until is seemed reasonable to hold and play. These stuffed mock-ups were sewn from non-conducting fabric, and possible sensor and ground electrodes were drawn directly onto them. Once the correct shape and size was approximated, a pattern for the instrument was made. The design for the electrodes was then entered into the embroidery software. Different sensors and electrode designs were experimented with by pinning them onto the mock-up instruments. The panels for each ball were then embroidered and the instrument sewn together and stuffed. It was then tested with different software and usually redesigned.

Ultimately, this was an extremely immediate and direct hands-on process that let me physically experience the overall shape, size and tactile feel of these instruments far early than the CAD design of a plastic shell would allow.

A Few Essential Textile Advances

Creating embroidered sensors that are highly conductive would have been easy if I had not also had musical and design goals. I wanted the sensors to be soft and flexible, close to one another, and to create physical interdependency. I also needed to create ground electrodes that were automatically touched when the player grabbed the instruments. Consequently, new sewing techniques, that went beyond sewing an electrode with dense satin stitch on a single panel of fabric, had to be invented.

During the design of these instruments, a new, layered, and multi-stitch, sewing process was developed. This process allowed for the creation of highly conductive and flexible textile electrodes that used a variety of visual and tactile stitch styles. In the past, we were only able to use a continuous, multi-layered, satin stitch to create the level of conductivity we needed. This involved creating a single, continuous stitch path that went back and forth to build up layers of zigzag under-stitching and the final satin stitch, which was the only “fill stitch” we were able to get enough conductivity with. We also had to hand-place many stitches to increase continuity. The satin stitch itself had real drawbacks because it could not be very wide, or threads would fray and become loose over time. It also had to be multi-layered and dense, making it stiff. As a result, creating wide objects had to be done with parallel swirls sewn form dense satin stitch paths, as in the *Generic Musical Ball*. These electrodes were relatively stiff, and using a single, parallel, swirled satin stitch was *very* limiting when designing the shape of the electrode.

The new, layered sewing process builds on what we already knew: that each electrode must be made from a continuous stitch path. However, it eliminates much of the need for stitch-by-stitch control that was necessary with satin stitches. This new process uses a light contour stitch to create an electrical under plane and then stitches over that plane with a variety of densely sewn, shaped objects. These objects tie the parallel lines of the contour stitch together, thus increasing conductivity. In the new sewing style, these objects may be made from a variety of fill patterns, not just satin stitches. The final, and most significant step in this process, is the addition of a light contour stitch over the top of these objects. Without this over-stitch, many objects stitched from lighter fill stitches, like tatami, are not conductive enough. This overstitching allows me to use different sewing styles and densities for ground and sensor electrodes. I like to use more tactile stitch patterns, like satin and bumpy stitches, for sensor electrodes, and smoother stitch patterns, like tatami, for ground electrodes. This process also creates a layered look that allows for the creation of great visual depth.

The new use of tidy stainless steel and wrapped nylon thread in the bobbin also allowed me to experiment again with sewing multiple electrodes on a single panel. This is very important because it allowed me to place ground electrodes in better proximity to sensor electrodes, which meant that the player was ultimately better grounded, and did not have to constantly think about touching the ground electrode. It was also important because it allowed me to put sensors closer together and create physical interdependency. Finally, it simplified manufacturing considerably. A four panel instrument is easier to sew than a ten panel one. Unfortunately, each instrument panel still needs to be properly lined to prevent internal short circuits. This does add a small, but annoying, extra step to the sewing process.

Essential to the iterative design process used to create these instruments was a new composite braid that I designed with Bekeart Corporation. This braid let me quickly and easily connect the fabric sensors with the central circuit by tying a single mechanical/electrical knot. This made the testing of electrodes and sensor designs quick and easy, and made the connection between the circuit and the fabric skin, durable and soft.