POPmatrix

Tongue Display Unit

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Abstract

The POPmatrix is an electric visual experience through your tongue. It is a device that enables individuals to stimulate their visual senses. These units display the received visual cues from the computer via a processing training sketch sent through this device worn inside of the mouth using electrode vibrotactile stimulation of the tongue. Using non-invasive sensory substitution methods, POPmatrix facilitates a new port for vision and a discreet addition to the palate of senses.

Keywords: Tongue Display Unit, Sensory Substitution, Electrode Vibrotactile Stimulation, Alternate Vision, Gastronomy.

Introduction

This device displays images on your tongue through a series of electrodes. Using sensory substitution, the device trains the user's brain to translate tactile to visual information and in time the user will begin to see the images displayed on their tongues.This project is largely inspired and informed by the work of Dr. Paul Bach-Y-Rita on sensory substitution and prosthetics. His devices such as the BrainPort were non-invasive and expanded on the studies of the elasticity of the mind. Like Bach-Y-Rita says- "We see with our brains, not with our eyes."

Domains

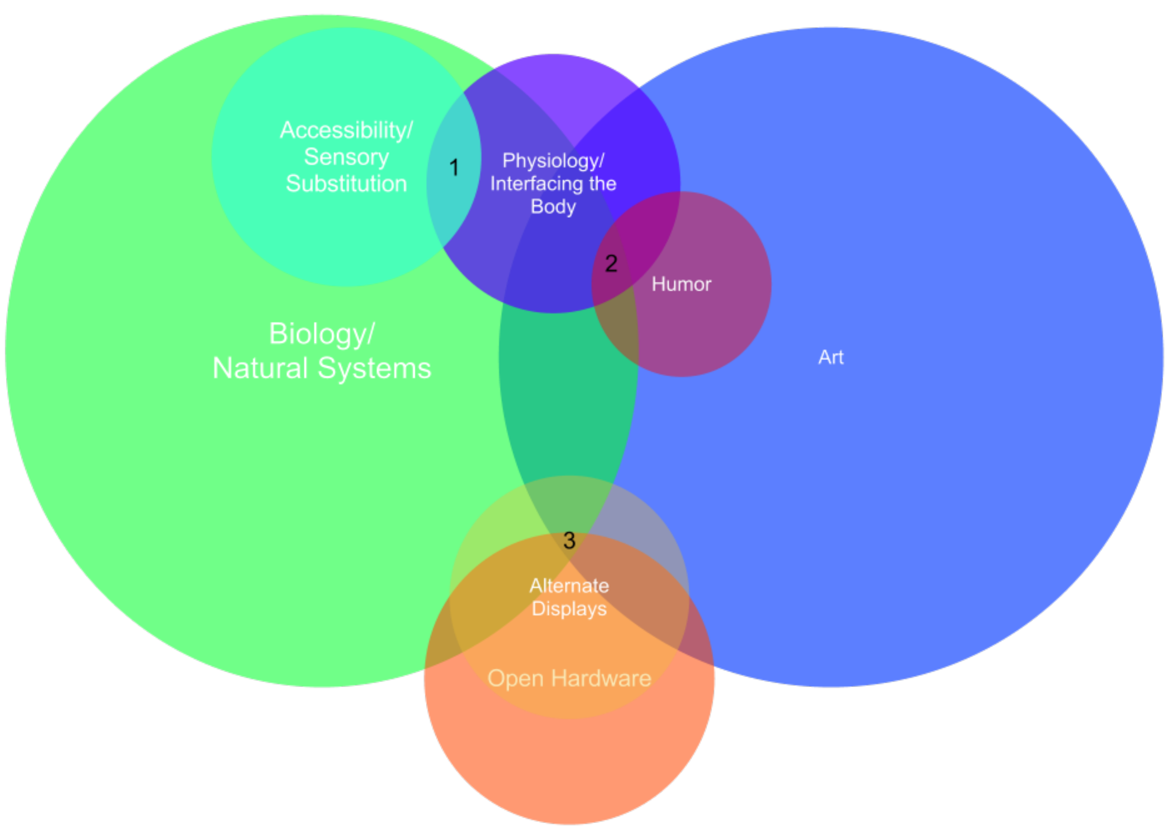


Fig. 1

Figure 1 shows the associations of the different domains in which the POPmatrix falls. Art and Biology/Natural

Systems are the larger encompassing domains that inform most of my work including Open Hardware in which most of my recent pieces fall. These categories are points of departure for the POPmatrix, if we look closely there are 3 places that have been denoted in Figure 1. The area number 1 is withing Biology/ Natural Sytem, Accesibility/ Sensory Substitution, and Physiology/Interfacing the body. This section is the beginnning of the project, the inspiration of creating a device that deals with investigating the natural systems of in this case the brain, and how it interprets information. Physiology and studying new ways to understanding the passage of information through the different areas of thought processing research falls into sensory substitution and the technologies that have been developed to assist persons that lack senses such as sight in this case. The second point in which this device falls is between Art, Biology, Interfacing the Body, and Humor. Art and humor are important in my work because it is not entirely scientific. Falling in these domains, allows a certain malleability to the presentation of my research and implementation. If I were interested in presenting this work as a purely scientific research, there is more time required to prove concepts to be accepted in the scientific community. Instead, my point of departure comes from borrowing scientific research and exploring the artistic capabilities of each. Humor is also largely important because it allows the work to have a point of entry to the public that acts as a catalyst between the scientific and artistic community. This work is not entirely bent of humor, but rather when presented brings some humoristic undertones. For example, when presenting the piece to the public the directions to understand the electric pulses there are funny remarks such as use the tip of your tongue and explore. Why is that funny? People tend to be very private about their physiology, and there are times when all things that interface with their body reminds them of their privacy. The last area, 3, falls within the two larger domains, but it also encompasses Alternate Displays and Open Hardware. Actually this area should also contain Accessibility because the idea of making technology that helps people with limited senses is a small industry therefore making the devices very expensive. There is no listed price for the BrainPort by Wicab, which is the basis of this project, it is still in its experimental phase and therefore not created as a product. Open Hardware can facilitate these technologies to people that need it the most, for as affordable as materials can cost. This allows people that cannot pay the exuberant amounts for privatized technology or that do not have the means to develop hardware themselves. Also, adhering new devices that are created in thought to display information in an alternate way also benefit thinkers and tinkerers of open hardware in developing new interfaces, may that be display or input devices. Lastly, the PopMatrix encompasses all of these domains from interfacing the body with the atypical venues of physiology, to making accessibility tools open source, and lastly presenting the work as light-hearted humorous artistic representation.

Precedents

1. BainPort: Sensory Exchange

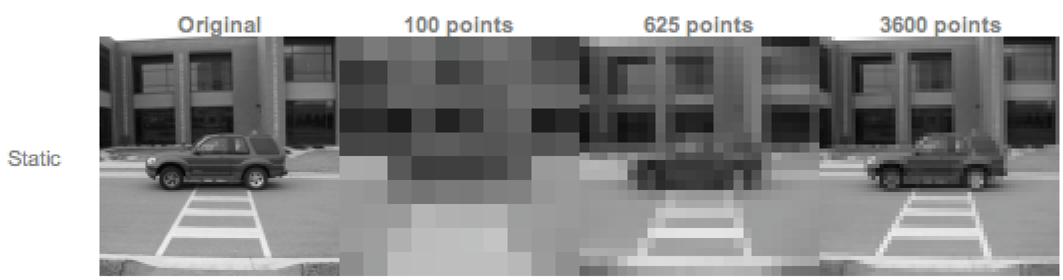
Fig.2

The BrainPort is a device that allows users to see images with their tongue (Fig.2). It was first invented by the late Dr. Paul Bach-y-Rita, who devoted his life research to neuroplasticity specifically sensory substitution. It is still being developed as a prototype under Wicab, Inc, a company dedicated to research in this field. This device allows the brain to substitute the optical nerves with tongue nerves and channel a set of pixelated information back to the visual cortex. All blind people, those blind from birth and those who became blind during their lives, can benefit from this technology, including subjects who still have some eyesight intact. Bach-y-Rita began his research in this field of neurorehabilitation over 30 years ago, a time when neuroplasticity and sensory substitution was not yet proven or believed.

In the first iteration of the BrainPort consisted of a static camera and a bed of electrodes. The subject would lay its back on this bed of electrodes and have the capability of seeing the movement and large objects captured by the camera. This iteration is a clever exploration of how we see. It is similar to a children's game where one traces letters on the back of another, who then tries to guess the secret message spelled on their back. Bach-y-Rita's famous words are- "We see with the brain, not with the eyes."

Fig.3

The BrainPort now consists of a camera, a tongue display unit, and a controller (Fig.3). A miniature camera is attached above the nose holder to a pair of sunglasses. The tongue display unit is a plastic enclosure the size of a postage stamp that holds from 400-600 electrodes. Both of these are attached to a controller that allows the user to adjust the contrast, the intensity of the electrical impulses, and to reverse the difference in the image. The electrical impulses vary from high to low depending on the brightness of the pixel in the static image, and it renders moving images at 30fps.



The electrical stimulation does not hurt the tongue. Users describe the experience as champagne bubbles or like licking a battery. In order to make sense of the electrical impulses, it takes the brain form 2 minutes to 10 hours to process these images. It is still debatable whether these images are being processed in the somatosensory cortex or the visual cortex. After enough training and use of the device, patients may begin to see images every time they drink something carbonated. Then wine connoisseurs can begin to truly describe the shape of their wine.

The tongue stimulation technique used by the BrainPort can be translated to many uses other than sight substitution. Cheryl Schiltz, had lost her capability to maintain her balance because of damage to her vestibular system caused by antibiotics. One of Bach-y-Rita's experiments with the BrainPort included the input of an accelerometer, rather than a camera (in the case of the optical nerve substitution). The information from the accelerometer was then translated to directional pulses through the electrodes placed on the tongue. The first few times Schiltz tried the device it did not work, but once after she tried the device for twenty minutes she recalls with much enthusiasm- "I danced in the parking lot. I was completely normal. For a whole hour." The BrainPort trains the remaining vestibular system to function incomplete, slowly the brain restores its ability to sense balance for longer periods of time without the device's assistance. By using this device every morning Schiltz has regained her sense of balance.

Fig. 6

The BrainPort was created with the intent of re-establishing sensory disruptions in people, specially those who are blind. Though this technique has become the prime treatment for patients suffering of vestibular depletion. The issue with other vision restoration processes, such as an artificial retinas, is that they require invasive surgery. On the contrary this device is completely superficial, which extends its use to non-handicap users. For example, the Navy was working with Wicab, Inc. to produce infrared vision through the tongues of their soldiers, to leave their eyes open to do other tasks. This device and other experimental sensory prosthetics explore the perceptual extent of our minds. The BrainPort opens a backdoor for the synchronization of neuronal activities. Bach-y-Rita is a pioneer it the field of sensory substitution, and with the BrainPort he proved that vision can be restored by substituting it with a haptic display. Is this truly new? Braille is the first example of how haptic displays have aided vision, but it was not a substitution. Instead of a new communication system Bach-y-Rita created a device that translates the actual world through vibrotactile stimulation into perceivable flashes of neurons, to be interpreted by the brain. So where is this information processed in the brain? Tactile information is processed in the somatosensory cortex, and visual information may be much more complex than this can decipher. In 1996 scientists found that blind people use their visual cortex while reading braille. Which means that even though reading braille is a haptic activity, it is processed partially by the visual cortex, proving the elasticity of the mind (Fig.6). The vibrotactile information of the BrainPort is first perceived by the brain in the somatosensory cortex, and with time it learns to interpret these electrical pulses with the visual cortex, restoring partial sight for the blind. Neuroscientists have begun to understand the brain as a plastic organ that allows for reorientation and reestablishment of processes. Marina Bedny, an MIT postdoctoral associate in the Department of Brain and Cognitive Sciences says- "Your brain is not a prepackaged kind of thing. It doesn't develop along a fixed trajectory, rather, it's a self-building toolkit. The building process is profoundly influenced by the experiences you have during your development." Our brain is so elastic, we can add other senses to it. For example there is a whole new subculture arising of biohackers who use biology in do-it-yourself methods. This has spun another sub-culture within called grinders, who modify their bodies experimenting with their own biology. Some of these grinders have gained popularity by inserting magnets to the end of their fingertips in order to sense the intensity and shape of magnetic fields in close proximity (Fig.7). These kind of experiments prove that the brain cannot be compartmentalized, since there is not part of the brain that would normally process magnetic information. Our brains are capable to interpret new sets of available information.

Fig. 7

In these times when we are constantly wondering if technology has sufficiently engulfed us, we ask ourselves how far are we from a machine? When Luigi A. Galvani discovered galvanic stimulation, he thought that bodies had an “animal electric fluid” which was different from metal induced electricity. Galvani thought that animals had a type of electricity in the body. His associate, Volta, in opposition coined he term “galvanism" for a direct current of electricity produced by chemical action, whether it happened in animals or not. This then led him to creating the battery. The importance of Galvani’s discovery of bioelectricity sparked ideas such as Mary Shelley’s Frankenstein. Life created from salvaged body parts and an electric spark by Dr. Frankenstein, was always referred to as a “monster”, "demon", "fiend", "wretch" or "it”. So when people reject the notion of improving or bodies with technology and merging with the machine are we as romantic as Galvani wanting there to be an animal or vital electric fluid, beyond the simple chemical electricity that makes batteries operate? Dr. Frankenstein’s creation must have been regarded a monster because it lacked some part of his consciousness. Perhaps this is the part that Galvani regarded as animal, the aspect of living that allows the brain to regard itself to direct its functions, and to adapt to new inputs for visual information. The BrainPort functions as an prosthetic sensory device that achieves its function the same way that Galvani and Mary Shelley imagined the spark of life.

In its design the BrainPort is not entirely comfortable, even though it is not nearly as uncomfortable as a surgically implanted invasive procedure. Since Bach-Y-Rita’s conception of this idea in the late 70’s of electrodes on the back to its transition as 3cm cubed stamp to be worn on the tongue, a lot of design iteration, contemporary technical advances and critical thought occurred. Why did Bach-Y-Rita choose an interface design for the tongue?

Since this particular device outputs information through electrodes and not by miniature solenoids, the tongue provides a prefect electrolytic environment for electrical flow. This raises the efficiency of the electrical input needed for the device to function above. The tongue being more sensitive than the fingers or the back allows for less current to pass the same effective amount of information. Another important factor of the design, is that by placing it inside of the mouth it solves many problems of portability, though this seems to create more problems than it solves. This Tongue Display Unit (TDU) is connected to a controller through a cable. Having a cable coming out of one’s mouth is not very practical, especially if the subject is blind and trying to navigate the world with the rest of the available senses (Fig.8).

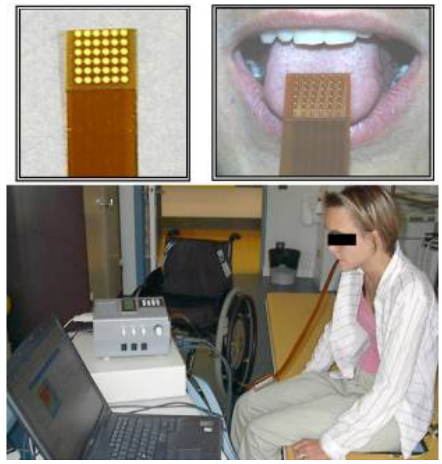


Fig.8

Sensory substitution does not mean cancelling the use of one organ to replace the lack of another. It means to use one sense and translate that neural impulse information into another sensory process. As the BrainPort has improved in time with technological advancements, such as miniaturizing the display from a back interface to a tongue interface, the TDU needs to be improved with wireless technology. Making the TDU a semi-permanent mouth retainer would be more practical and effective than an electric "lollipop" that could impede speech and could be impractical for multitasking (Fig. 9). This way users of the BrainPort could talk, eat, and see simultaneously. In order to miniaturize and further the BrainPort's efficiency, the controllers of the device should also be in the mouth. Designing for tongue controls is a limited field that begs for more exploration. For example the Think-A-Move is a tongue remote control device that listens through an earpiece for different sound frequencies in the mouth. Depending on the tongue's position an movement, a specific sound frequency is created that travels through the ear canal to be interpreted by the earpiece. This is connected wireless to the action module, that then executes the task based on the tongue commands. Slide potentiometers or very sensitive push buttons, seem to be the most efficient control system to be paired with the BrainPort's TDU. Other tongue controllers that use magnetic, or sound technology might be too delicate to work aside a display unit.

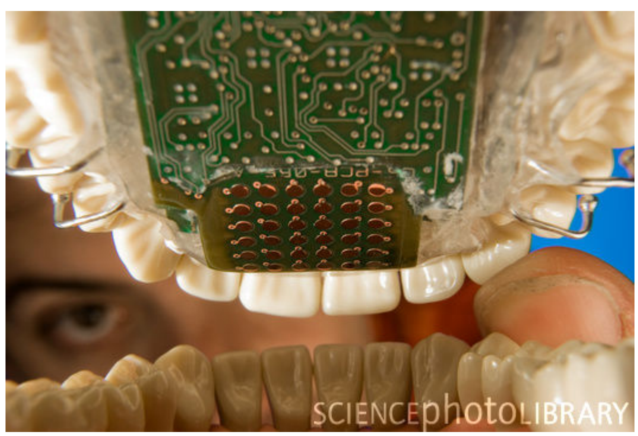


Fig.9

The TDU's interface is still practical for prototyping reasons, since a semi-permanent retainer solution would have to be customized for each user. Wicab, Inc is currently prototyping this device and therefore have other practicalities in mind than designing the most comfortable wearable device. The device is not for sale, users can contact the company to inquire about participating in their research, but not to purchase it. There are implications of selling a device that uses electrical stimulation, without having done much research about the side effects of long term electrocution to the tongue. The BrainPort being a sensory prosthetic device needs to be a safe application for sensory substitution, otherwise it will change the meaning of the term entirely. Thus far there have been no cases of taste or sensitivity loss on the subjects that have been using the prototypes. So in essence the device has fulfilled its expectations of translating visual information through haptic sensing, back to the visual cortex.

The BrainPort serves its sensory prosthetic function, even though it is facing some interface design problems. The findings from this prototyping phase are not made public, so it is impossible to tell if the prototyping subjects have given feedback about these issues. Most likely some of the subjects have found the TDU interface uncomfortable, because it suppresses another bodily function, speech, imperative to a blind subject. Beyond its prosthetic capabilities the BrainPort is an attempt to create a new type of interface that stimulates alternate display and control units. The TDU is a window through the tongue, the applications of this device are limitless, and can be used for as many applications the visual screen is use. At one point the visual screen had pixel per pixel resolution. Once the BrainPort has been tested and prototyped enough times to prove its health and safety of use, then we can begin to see more public improvements of Tongue Display Units.

Even though this device is intended for blind people there are many applications that surround the concept of sensory substitution. The most interesting idea that comes to mind, is to share senses between people through these methods. Thinking of prosthetic devices as a solution for body augmentation can be a provocative avenue. At some point in the future non-invasive prosthetics will serve functions we always dreamt of for example one can borrow a third arm and install it to function directly with our other motor controls. The BrainPort fits a provocative ideal in the near future, one could see the world through the eyes of another with this device. If the TDU actually became wireless and there would be a receiver applied to it receiving the the camera information to display, with this improvement it could also receive the output of other cameras around a periphery or from a specific network such as wi-fi. If there were enough users of this device, a network of visions could be established, in which each user could change the channel vision to their liking and still perceive the rest of the visual information happening around them. The information received does not only need to be coming from a user, it can also be a new way of watching videos, except now, one can carry the tube on their tongues. Never mind the social implications this device can have on society, imagine the complexity of cognition children can develop from having to process so much information simultaneously. It is fascinating to know that we use such a small percentage of our brains, and how there is more space for adding more senses and more complex processing power. For example, in the world of computing, hardware always advances faster than the capabilities of software. Our brains have the hardware it takes for us to transcend bodily limitations, it is in our creativity to flex our minds into shape.

Fig. 10

The Eye Candy Can created by Beta Tank shown in Figure 10 is the first artistic iteration of this work. I have implemented the concept of the use of this technology also as a seeming lollipop. There was a conversation with the Beta Tank for future collaboration in implementing the open hardware created for the POPmatrix using their designs, but there has been no further communication about the continuation of this collaboration. Their prototype is just a look and feel prototype, and not a working prototype, in contrast with the POPmatrix, which is a fully implemented prototype in its first iteration.

Fig. 11

Iterative Design Process and User-testing

Fig. 12

The first iteration of this design was in the original form of the POPmatrix (Fig.11). While conceptually iterating over prototypes of comfortable enough for users to introduce in their tongue there was also the idea of creating a spoon. This SPOONmatrix (Fig. 12) began as an exploration of tongue display units and it has evolved as an opportunity to interface with the physiology and electric potential of gastronomic experiences. This device is also using the tongue display unit that displays light pulses of electricity based on the animations programed for particular dishes.

Creating this spoon was extremely difficult as embedding electronics in wood in not as easy as it seems. Like for the POPmatrix, the first step was to design the pcb board for the electrode matrix. The spoon has a larger resolution of 9x9 electrodes, where the pop has a resolution of 5x5. The actual electrodes are placed on a 18x9 or 10x5 matrix. The reason for doubling the amounts of pins on one side of the matrix, lies in the architecture of electrode tri-state logic. By programming one of the two sections that are to be animated as outputs HIGH meaning passing current and the other pin LOW meaning drawing current the tongue makes a connection between both pins, thus creating one electric stimulation between both. The third aspect of tri-state logic is that in order to control the current's connections throughout the circuit, there must be no current passing or drawing between the other pins. By setting all the unused pins in the matrix as inputs there is no current passing through at all. The following steps in creating both of these devices is the milling of the designed circuit. This was done in a pcb milling machine by uploading the design files. It routs, drills and mills the design and once it is done it is ready to be soldered. My system for soldering each of these pins was to cut small pieces of wire of the same size and prop the board above the table in between some pieces of wood of the same thickness to achieve the same height for each pin. Because the machine that we have available for pcb making is only a milling machine there is no soldering mask layered on top of the first connection lines, so if there are crossing wires the board has to be milled on both sides. This means that there are soldering

connections on
both sides that needs to be fused. Once all of this was soldered, I realized that the wire leads were too small to direct their path through holes drilled on the pieces of wood that later would become the spoon. This became a mistake that would set me back another day of precision soldering, but this time the wire leads must be longer (Fig 13).

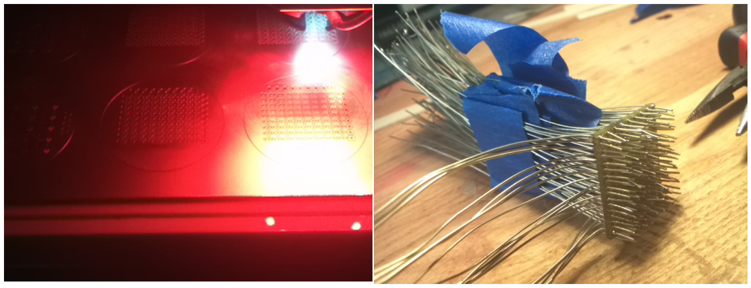


Fig. 13

The longer leads made it easier to thread the wires through the holes drilled on the pieces of wood, then once completed the leads must be cut to the size of the wood encasing the circuit and soldering the cables that must then be connected to the microcontroller (Fig.14). This controller is what sends the electrical pulses and controls which leads become cathodes anodes or inputs. The next step in creating this spoon is whittling the actual shape from the rectangle sandwich of copper, fiber glass, wood, and glue here in Figures 15 and 16 the process is displayed.

Figs. 14, 15, 16

Evaluation

The POPmatrix and the SPOONmatrix dabble in the field of experimental devices for sensory substitution. Both of them represent a creative iteration for incorporating this accessibility technology into the art world, whether it may be as a tool for investigative alternate display interaction or as an electric gastronomic opportunity. Going back to the roots of the BrainPort's intent of assisting non-sighted individuals, and due to the lack of achievable resolution, the POPmatrix can be presented as a braille display device, rather than the display of 5x5 images. On the second account for the SPOONmatrix, there need to be more research and user testing to collect data of how this electric stimulation along with food affects the sense of taste rather than its sole current function as somatic stimulation. One of the subjects participating in the user testing of the POPmatrix reported that he tasted something "lemony" in his mouth after wearing the device for 5 min. One person suggested that there might be a difference of taste depending on the amount of voltage applied. However, because the location based tongue taste map we all learned in pre-school about the sense of taste has been discounted it is unlikely that solely area based electric stimulation can cause different tastes to be sensed. There is the possibility that depending on which chemicals are ingested in the presence of an electrical current that some component may react, thus changing its taste. This is part of the research that must be conducted along a gastronomy expert. The tongue display units have spun a series that adds to the palate of the senses, eventhough the augmentation of perception takes time and practice, experimental devices that attempt to shift our current modes of visual display can become exhausted, therefore anything new in this department is progress. We will begin to see that our touch-screens will be paired with vibrotactile stimulation, but can we train our brains to be as fluent through our somatic senses as our vision?

Figs. 17, 18

Future Directions:

These devices have spun a new series of electric utensils called ByteWare. It would be a series of electric utensils that spark gastronomic experiences. Eventually Electric Bites, will be a culinary performance in collaboration with chef Dan Zaccariello. This event will exhibit the ByteWare with dishes being specifically created for each utensil. Other ideas to supplement this dinner are self-folding Nitinol Napkins, and thermal display dishes. Some of the new utensils to come would be the POWERfork and the GEIGERchopsticks (Fig. 19). These GEIGERchopsticks are a response to the nuclear waste that affects the ocean. These Chopsticks raise awareness to the radioactivity found in fish we eat for example in sushi. The POWERfork plays with the idea of galvanic electricity by having interchanging silver and zinc fork pins, the ions from the zinc will migrate to the silver thus making them cathodes and anodes. The electricity collected will then power an LCD screen that displays the seconds you have powered the fork by using it.

Fig. 19

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