Sensory Pathways for the Plastic Mind

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Sensory Pathways for the Plastic Mind:

A series of experimental devices that expand sensory experiences through cross-modal computer interaction.

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Abstract

These wearable extensions are alternative electronic data displays through sensory-mixing mechanics. This shift of information output tests the potential of further integrating computing applications with our wide physiological sensory array. This research explores perceptual interfaces that translate information through cross-modal sensory methods. In four case studies, this thesis appropriates common devices, transforming their sensory functionality:

1. Play-a-Grill: bone conduction music player jewelry mouthpiece;
2. Echolocation Headphones: seeing space through parametric sound;
3. Spoon Matrix: tongue display spoon for tactile sight in gastronomic experiences;
4. Scent Rhythm: olfactory mapping to the body's circadian cycle.

Adopting the core utility of common devices and expanding their physiological interface capacities, ignites alternative perceptive pathways for information. These experiments deliver novel experiences based on multi-sentient interactions that expand the palette of the senses.

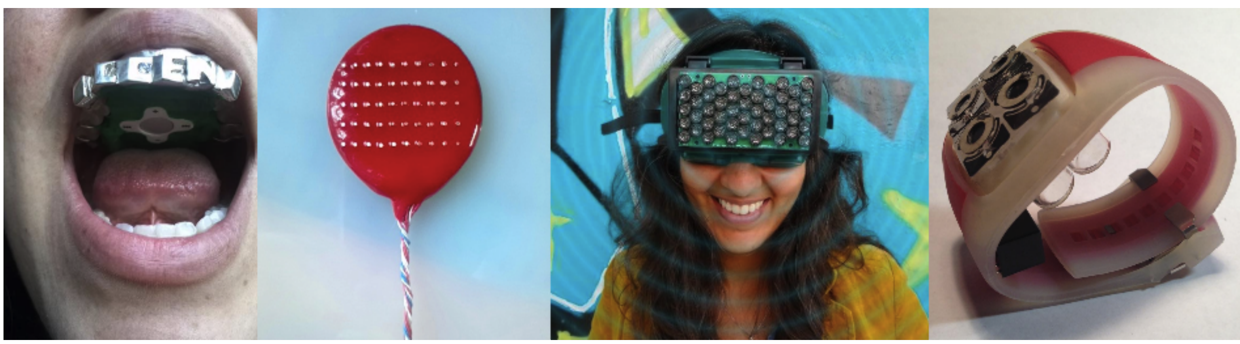

Fig. 1 Devices

Case Studies: Play-a-Grill *(left)*, PopMatrix *(center left)*, Echolocation Headphones *(center right)*, Scent Rhythm *(right)*.

Keywords

Sensory Substitution, Brain Plasticity, Wearable Devices, Perception, Alternative Information Displays, Bone Conduction Hearing, Parametric Sound, Tactile Visual displays, HipHop, Gastronomy, Echolocation, Accessibility, Hardware, Physiology, Bionics.

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Chapter 1

Introduction

++ Think of the brain as a control station that manages many inputs and outputs: these signals are interpreted as map of our interactions with the surrounding environment, where we are and how we are. The perception of our existence is a combination of the interpretation of our senses. We can arrive at the same understanding of an experience based on a few signals. Depending on the different goals of perception, various inputs can collect useful information, for example: to learn about our spatial surroundings one can use proprioception, audition, sight, and kinesthetic senses. Taste, is not a very efficient way of learning about our spatial surroundings, but what if there was a way to link gustatory signals to spatial information in the brain? Some people have a condition called synesthesia that allows them to have inherent connections between the senses. There are synesthetes that always have particular tastes associated with certain words. Their experience of the world is enhanced by an extra layer of information created from the crossover between perceptual synapses.[58]

So, in order to achieve spatial tasting one has to be a synesthete, or perhaps undergo brain surgery to achieve cross-communication between different sensory platforms. Is there a possible way to achieve such instances of interpretation through non-invasive technology? Neuroplasticity and sensory substitution theories suggest that the brain is moldable and adaptable based on conditional circumstances of change in behavior or environment.[37] Also known as brain plasticity, this area of study aims to answer one of the most intriguing questions of neuroscience; how does the nervous system adapt its functionality based on sensory input, experience, learning, and injury?[26] [7] Plasticity can occur rapidly with an intervention based on decreased inhibition, meaning that the receptive field occupied by a past signal will expand to enable other neurons to be excited by new stimulus.[46] The perceptual mapping of sensory substitution is more complicated than expanding the signal from one neuron to another. If a person who has been congineally blind and only knew objects based on their tactile information; gained their sight, could they distinguish those objects based on sight alone?

This is Molyneux's philosophical problem and it has provoked sensory mapping research since 1688.[32] His question was seemingly simple, but very difficult to answer by postulation alone. There were a few attempts of experimentation, that were deemed inadmissible given lack of controlled circumstances, but Pawan Sinha answered the question with proper experiments in 2003.[35] The answer to Molyneux's problem is negative, because subjects who gain their sight cannot distinguish the same object they knew by tact from sight immediately.[32] Instead, the connection between the senses is learned by experience, therefore making sensory substitution devices subject to function as a training devices until the experiential connection is mapped in the brain. Pawan Sinha stated in his research that his subjects were able to create this tactile to visual connection within a few days.[35] This means that sensory substitution is a learning process, and not an immediate outcome.

The ways in which the brain works to capture experience has researchers, neuroscientists and most people alike incredibly curious. The impetus of this thesis research is to understand perception and sensory substitution principles through a series of experimental devices and case studies. These devices derive from existing scientific research on perception, most importantly theories and applications of cross-modal assistive technology through deconstructive design of appropriated common devices.

1.1 Making Sense of Stimuli

What are the known alternative sensory avenues that can substitute one another for a specific perceptual function? What sensory substitution and augmentation methods already exist?

Tactile > Visual, Auditory > Visual, Tactile > Sound, Olfactory > Gustatory.

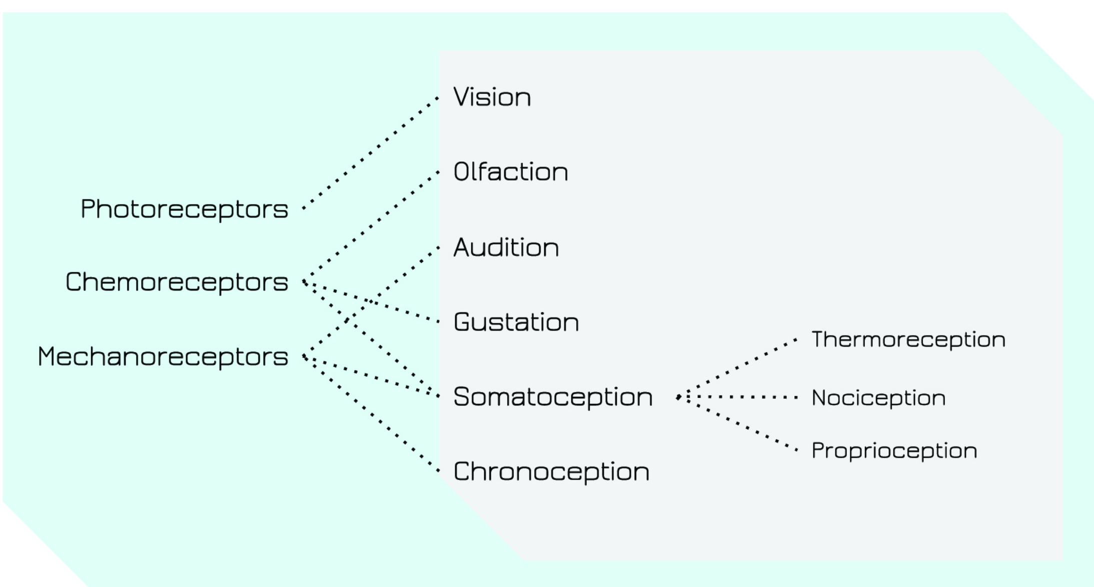

Fig. 1.1 Sensory Map

Understanding the senses and how they are interpreted in the mind is crucial for the inquiry of these perceptual expansion devices. Figure 1.1 maps the sensors in human species, and their respective types. Most of the senses fall under the mechanoreceptor category, especially under the somatic sense, in which we feel thermoception (temperature), nociception (pain receptors, ouch!), and proprioception. The last mentioned, proprioception, is quite an interesting sense, since it allows for kinesthetics, knowing the placement in our bodies in contrast with the environment around us and ourselves. This also includes the vestibular sense, which is our sense of balance located in our ears, one of the most complicated mechanoreception systems.
The perception of the world around us is a delicate and balanced dance between our sensory and motor cortex. One interprets information, and the other one mandates new functions allowing the flux of our perception.
It's possible to plug and play with your sensory field and achieve alternative pathways of perception. 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. These sensory-mixing techniques are applied to test the adaptability of the brain to translate some perceptive functions. Participants engaged with these sensory devices are re-channelling their senses. Some of these interactions have more agency than others over the user's physiological perception, they are already hardwired, such as bone conduction hearing. Others require training and practice in order to achieve a level of brain plasticity bio-cooperation, such as tactile sight. These additive sensory interfaces aim to open new modes of perception for all users, striving to understand sentient physiological and psychological phenomena that expands the perceptual potential of new interfaces for computing media.

Chapter 2

Methodology

2.1 Domains

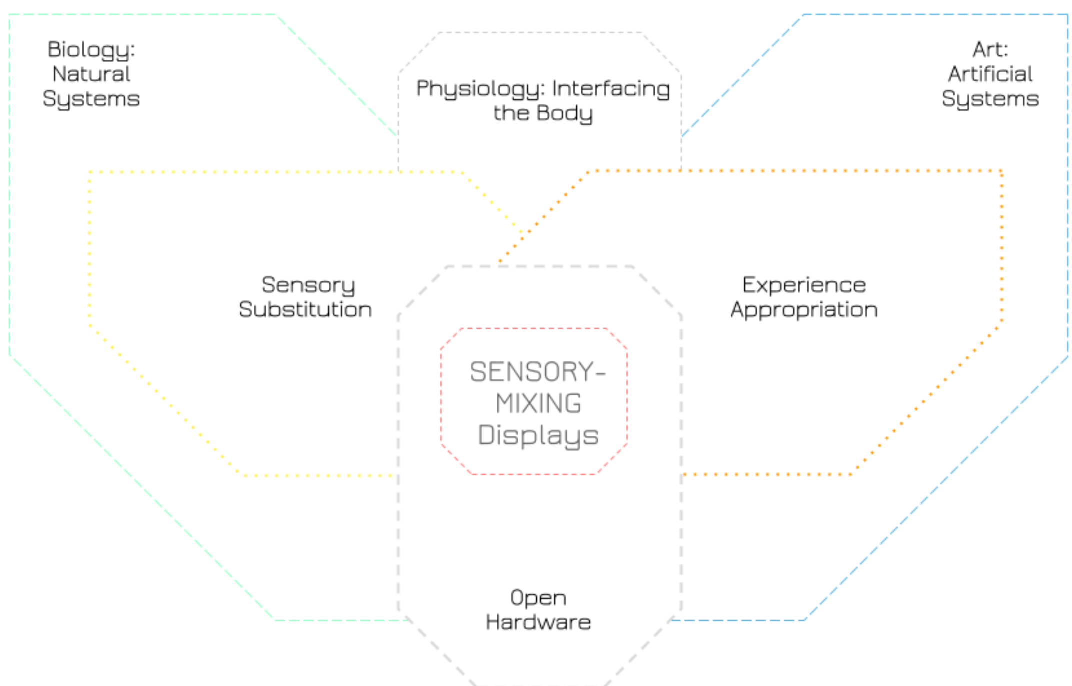

Fig. 2.1 Domains Map

The symbiosis of natural and artificial systems is a vast topic, in which so many transdisciplinary fields entangle, but nonetheless they encapsulate the core of these experiments. These open source tools are made by borrowing scientific research and exploring the artistic capabilities of interfacing the body with the atypical venues of physiology. The map above shows the associations of the different domains of the subject categories in which these experiments lie. Alternate displays are in the core of this diagram because it is the goal and product of this research. These displays are created using tools of open hardware and hacking techniques. Making technology that helps people with limited senses is a small industry of privatized technology therefore attaining these devices is difficult and expensive. Open Hardware can facilitate making these technologies available to people that need them the most, for as affordable as cost of their materials. Also, provoking thinkers and tinkerers of open hardware to develop new interfaces for information display.

Interfacing the body is the most delicate aspect of this study because it promotes the examination of the electrical self and ignites possibilities for understanding physiology and the brain's circuitry. Taking safety precautions is imperative, as this research is not based on typical scientific methods, but rather experimental design forms that derive from scientific inquiry. The body in art serves as a reflection of the subject, which posts primordial questions of the human condition. In embodying the experience through these alternative display devices, there must be a popular link to culture. Art and humor allow a certain malleability to the presentation of this research and its implementation. Taking a humoristic view on the body allow a certain malleability between willingness to participate and curiosity. This egocentric approach to the experience of art question's the privacy of the viewer at a very personal physiological level, and simultaneously provokes the desire to experience something new. For example, when presenting a tongue display unit to the public the directions to understand the electric pulses on your tongue include 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 somehow there was never a shortage of willingness to participate. Popularizing scientific concepts such as sensory substitution and physiological understanding generates approachable circumstances of curiosity. It becomes a playful avenue for learning.

2.1.1 Sub-Domains

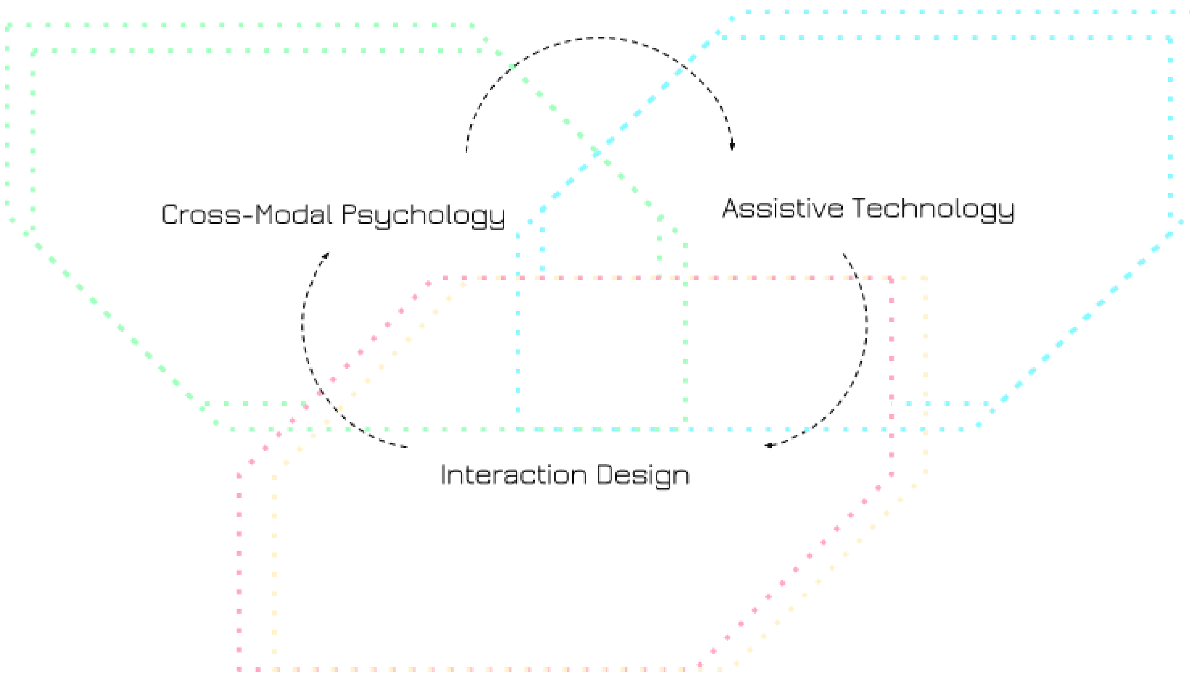

Fig. 2.2 Sub-Domains Map

The map in figure 2.2 shows the entrails within the larger scope of this project. The case studies in this research are a dance of translation, adaptation and learning processes that sit within the fields of cross-modal psychology, assistive technology, and interaction design. These interactive devices are emerging from experimental cross-modal instances studied in psychology. Many of the applications for sensory substitution experiments emerge for accessibility needs, which is the quest for making technologies and information available to anyone despite of their sensory limitations, such as blindness, deafness, etc.

Assistive technology is a rich model of reference in designing for alternative perception, borrowing from this field has led me to harness a new potential for the interfaces designed in this study. Demasking the popular notions of accessibility as pure disability technology, and finding new ways for people to perceive its capabilities can only be done by dislocating these ideas and repurposing them. The interaction design for these pieces have a foundation in appropriating the wearable functions, uses, and sometimes basic interactions of certain common devices, such as goggles, watches, spoons, and mouthpieces. Deconstructing these and exchanging their sensory functionality by thinking of novel sentient experiences that are not solely meant for accessibility purposes, rather trial the theories of cross-modal psychology- how we learn, and continually wants to know: how does the brain adapt to new channels of perception. This testing hardware provides an outlook for the functionality of sensory translation and adaptation. Though not all of the case studies proved to be entirely efficient in their purpose, efficiency is not the main goal of the interfaces. The purpose of this research is to analyze cross-modality through experimentation, rather than to produce applied research. Current devices that provide alternative avenues for perceptual display are meant to fill a need in the sensory impaired community, thus existing as accessibility devices. How can these modes of perception be adopted for popular applications? Isn't all technology assistive at a certain capacity of its purpose as a tool?

Voice command and recognition is an emerging form of this assistive technology that has seen popular applications. Previous innovation in the field of voice and sonic computing interfaces was generated for visually impaired users, such as screen readers. Today the mobility of computers has adopted these alternative display models for popular applications, because as these devices become smaller and wearable, they present new input and output problems fueling new interfaces to be developed. Tactile displays are another example of accessible technology that has made a leap on to popular applications. Braille display devices and vibrotactile stimulation, also used in event simulations, has been used to aid blind people to interface with computational media. Now we see mobile devices becoming reactive to touch by using emitting a vibration through a motor, previously used solely for incoming calls in silent mode, as a display method to show the user that an icon has been selected. Soon we will begin to see haptic simulation effects in our mobile technology that will create textures and different somatic stimuli with localized matrix generated vibrations, rather than the single motor in current devices. This is an enhanced braille display. These case studies inquire about future cross-modal applications for wearable devices~~,~~ : what other perceptual methods are useful in computing?

2.2 Approach

The approach to achieve new models of information display begins by studying the current devices and applications that exist for sensory mapping by:

- Borrowing scientific research and exploring the artistic capabilities of interfacing the body through atypical venues of physiology, by making hardware accessibility tools open source and generating new forms of information display.
- Developing technology that can enable the advancement for information accessibility and simultaneously provoking thinkers and tinkerers of open hardware to develop new interfaces for information display devices for general purposes.
- Embodying scientific concepts such as sensory substitution and physiological understanding through design to generate approachable circumstances of curiosity. Introducing a playful avenue for learning about the body that acts as a catalyst between the scientific and artistic modes of thinking.
- Deconstructing and appropriating the interfaces and uses of common devices to achieve new sentient experiences through the design of physical, functioning prototypes.

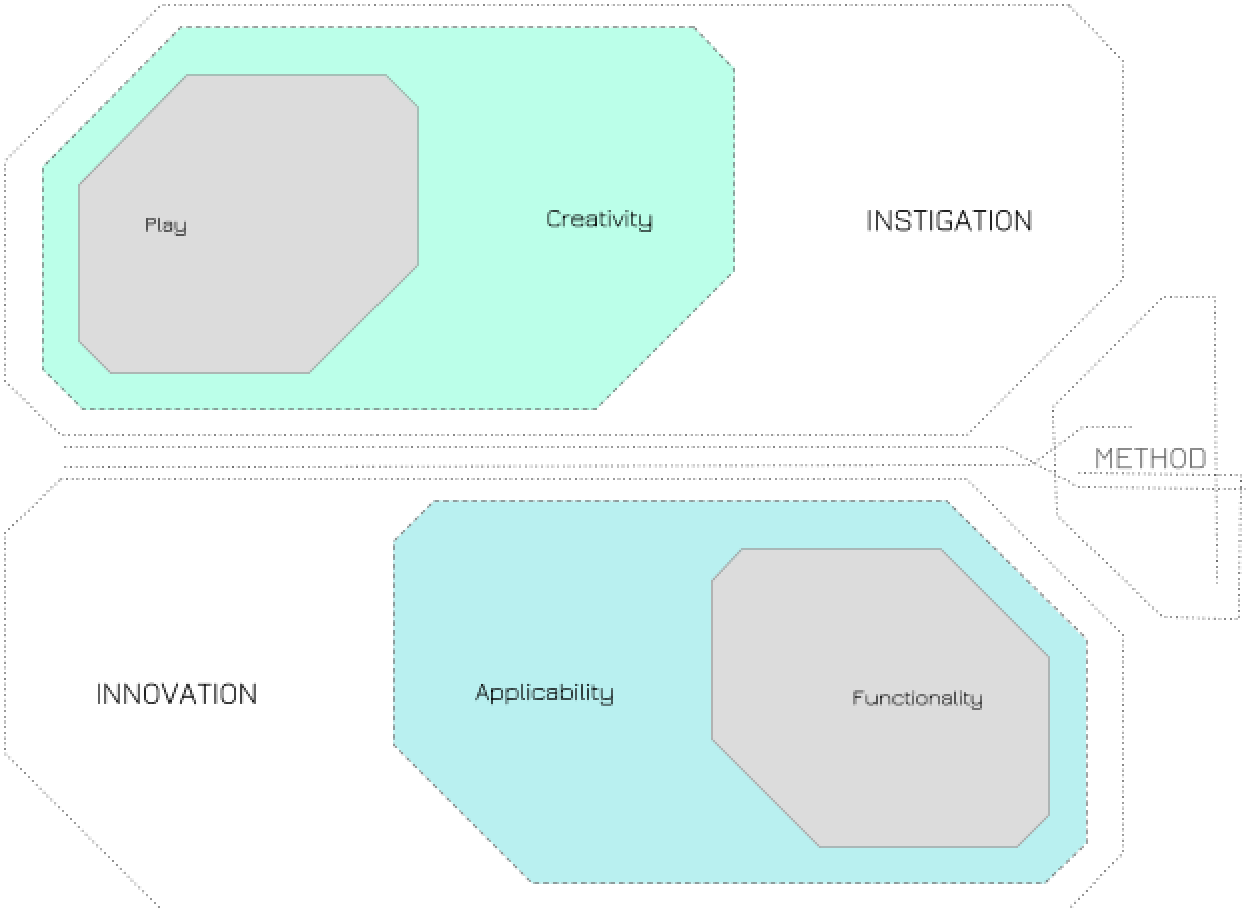

Fig. 2.3 Procedural methodology

The two basic methodology branches for embarking on this project begin with the ideas of instigation and innovation. Instigation is the activation of new thinking, provoking new ideas, resolutions, or providing a new perspective to the viewer/user in which to interact or analyze the tools or experience. Creativity is product of play and the constant inquiry and curiosity about the world, the ability to generate new ideas. In a way instigation is a product of creativity, in Fig. 2.3 INSTIGATION >> Creativity >> play, the embodiment of these concepts can be seen as a breath. Play and inquiry are both at the point of departure for the system, the concepts embark from play and then move through to creative instigation, then these activations are deployed by creative play once again. Ideally the work instigates creative play, allowing the user/viewer to approach it and arrive to a moment of “aha!” and “wow!” - “I get it.”

It is important that the devices are approachable and instigate new ways for the user to understand the map of their own perception, but in order to achieve credibility and the feasibility of new sensory avenues these devices need to function. In the lower section of Fig. 2.3 the encapsulations read, INNOVATION >> Applicability >> functionality, and the same assumption can be made about reading this diagram as a breath. Where functionality and innovation can be the starting or ending point of the closed circuit. Innovation can be born from any creative assay, as in the core of both definitions lies newness. In this work the innovation comes from the applicability rather than the functionality, but it is equally important for the concept to be a functional, working prototype to achieve the proof of concept. If the devices don't function and are merely conceptual, the "aha/wow/get it!" moment will not arrive with the same intensity. Concepts need to be experienced in order to be effective.

2.2.1 Habits of Mind (cultures of thinking)

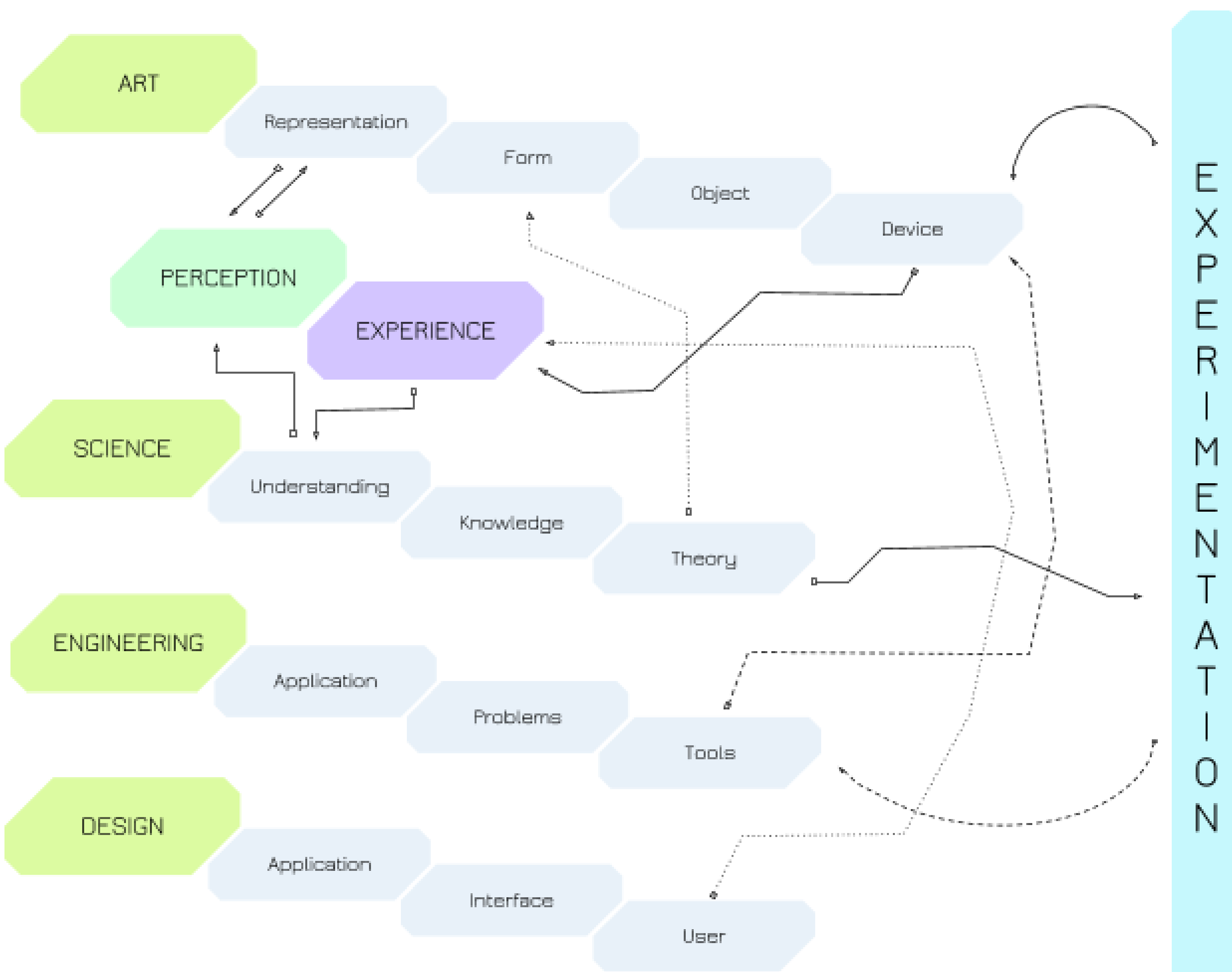

Fig. 2.4 Principles of Thought

The symbiosis of the cultural and physical understanding lead to subcategories of application within design and engineering. In Fig. 2.4 the principles of thought are a recursive map of the categories of my thinking while making these devices. Art and science both produce the conceptual bases of this work and engineering and design inform its application. Perception is embedded in the core of both the sciences through learning about the world by observation and the arts by representing the world. It forms our experience allowing us to understand and propel new knowledge to be transposed to theory, once it is proven by testing. The process of experimentation yields tools and devices to explain or better probe at the theories in question. Pure experimentation can also generate inquiry that lead to new hypotheses, similar to the breath reading of the methodology diagrams in Fig. 2.3. The relationships in the Principles of Thought diagram show the conceptual process in which these devices are formulated to generate the experience of sensory substitution. It also depicts a general map from basic to applied research at large.

2.2.1 The Object in Art

Design, in my perspective is a subcategory of art, in which objects are designated for utility and function. The nature of these devices lies in between these methods, as they are becoming utilitarian forms of interrogation, diagnosing their sensory purpose, not necessarily for their enhancement but rather for the task of repurposing and situational analysis.

The transcendence of the object in art takes many forms, from craft to social sculpture, and also animate objects such as devices. Tools are the result of solving a problem in engineering. Through this process I have created tools, such as a vacuum-forming machine to create the enclosure of the Echolocation Headphones. This machine has no visual or artistic conceptual value, it just serves its purpose; it is a true tool. The case study devices are different from “true” tools because they are actualized for experimental investigation. They are atypical tools, generated for perceptual expansion, they don’t aim to solve problems, but rather instigate new forms and questions of data perception. These alternate pathways for perception might assist in new problem solving, by creating circumstances yet to be experienced.

This procedural conversation between science and art as an approach to formulating and testing concepts settle through the languages of design and engineering. The theories cannot be tested unless the concepts are sound within interaction design and technical implementation. Beyond theory testing exists the trial of materials, electrical connections and components, visual cohesion, what works and doesn't work.

2.3 Adaptability

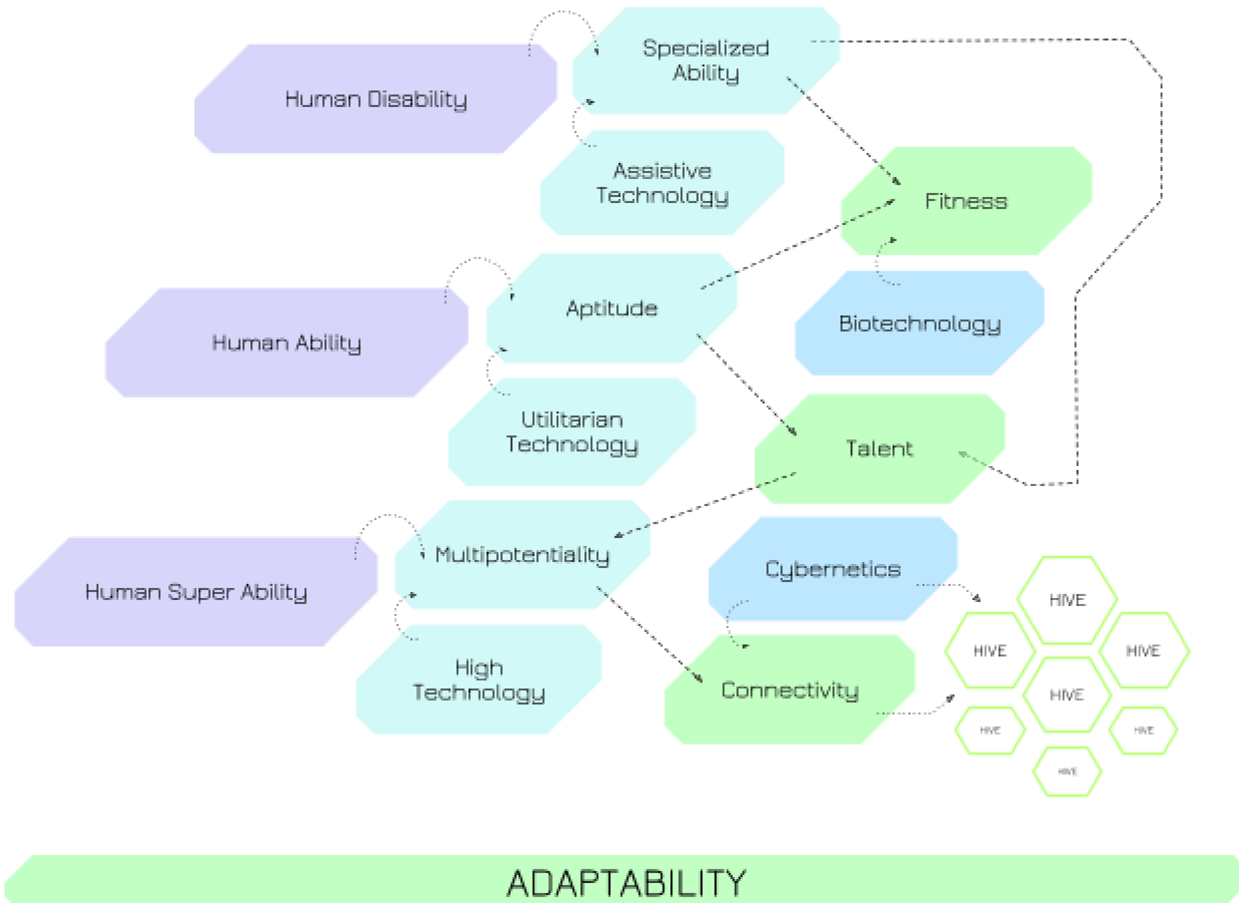

Fig. 2.5 Human Ability and Technologies for Adaptability

Why is it important to innovate in the alternative display of data? Coming from an evolutionary perspective these trial devices aim to improve the human condition by reappropriating the senses to examine problems in different ways, currently unavailable with normal perception.

What kinds of sensory developments will become product of our own technological and symbiotic evolution?

One can assume humans can walk upright, they can talk, they have around 10 Hz of the visual and between 20 Hz and 20000 Hz of audible electromagnetic frequency range. These are all normal human abilities, that can be supported by utilitarian technology, but what about talent or disabilities, do these capability traits inform the path of our adaptability and evolution?

What we think of disabilities is the disadvantage that a person has in comparison to the average abilities of normal individuals, rather than the specialization of their perceptual abilities. The plasticity of the mind allots processing currency depending on the necessity of specific functions based on sensory ability. Therefore disabled individuals compensate their perceptual processes with their abled senses more acutely than an able individual, eg. heightened sense of hearing in a blind person. This adaptability of the brain to assume more processing power to any of the senses is also seen in the Savant Syndrome. This syndrome, although extremely rare, exists in autistic or mentally disabled individuals who compensate their incapabilities with strikes of genius in mathematical calculation, memorization, lingual and artistic abilities among others. This condition can be acquired during a lifetime accidentally or congentially, it is also known that it can be acquired and lost in inexplicable instances.[55]

2.3.1 The Electric Savant

The development of the brain's left hemisphere during fetal formation may be impeded by testosterone surges, forcing more functions to be processed by the right hemisphere. Damage to the central nervous system forcing brain processing to be redistributed can also cause this effect.[55] What type of device could safely and temporarily induce the savant syndrome without inhibiting other brain functions? Can this condition be created by pulsing electricity through the left hemisphere of the brain?

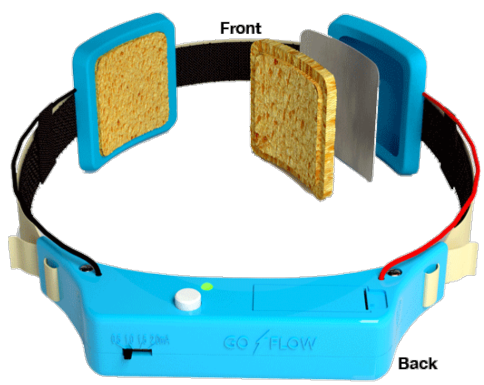

Fig. 2.6 GoFlow [22]

According to aptitude tests with electric inductance of one or more brain hemispheres of cortical excitability- via cathodal transcranial direct current stimulation, tDCS, helps patients that have suffered strokes, enables memory, mathematical, language ability, and attention span.[34] This method is also used by the Air Force to splice the training time in half for drone guiding. They apply two milliamperes of direct current for 30 minutes.[14] A group of hackers met up at a start-up weekend event in MI, and created the GoFlow. This instrument is a very simple two electrode system with a 1.5 Volts battery that uses tDCS.[22] Such technology is so simple that it is hard to imagine that it is not a school supply requirement. The public must be incredibly nervous about the long-term effects of this technology. Interfacing the body with electricity falls under the non-invasive category because the device is not implanted within the body.

The GoFlow and other assistive technology such as text-to-speech are systems in the realm of non-invasive technologies that achieve multi-potentiality and place normal human ability as super-human abilities. Some of these technologies also serve as prostheses to allow further communication between our species, thus allowing more connectivity and creating a network that sums up human capability as one, sometimes referenced to as the hive, the collective consciousness. The internet is the digital tissue of the hive, it connects us through our evermore mobile devices. Will there be a genomic IP address sometime in the future? What are the non-obvious additions to human genomic capabilities or will we limit our abilities to non-invasive technology such as the experimental devices in this research?

The intention of this study is to experiment with non-invasive devices that can supplement or substitute our general and current perceptual abilities. Longevity is an obvious desirable evolutionary trait, but how about the expansion of chronoception, are films and novels an attempt of non-invasive technology that alters our own perception of time?

Based on our adaptability to the environment, if there are more nuclear disasters will we need to genetically engineer a geiger-sense? Could the ability to further understand spatial information based on sonic proximity be helpful for more that just the blind? In understanding the advantages and disadvantages of the normal brain and the disabled brain lie many unexplored traits that can be useful for survival. Designing devices that mimic extraordinary ability or serve as training apparatuses for further engraving alternate paths for neuronal operations such as seeing with tactile information, is one path to discover what non-obvious evolutionary traits our species might benefit from.

Fig. 2.7 Magnets Inserted in Fingertips [15]

Neuroscientists have begun to understand the brain as a plastic organ that allows for reorientation and re establishment 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.”[36] Our brain is so elastic, we can add other senses to it. For example there is a whole new subculture arising of bio-hackers 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. 2.7). 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.

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 the 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.[15] The importance of Galvani’s discovery of bio-electricity 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.[48] 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.

2.3.2 Tools for the Evolutionary Future

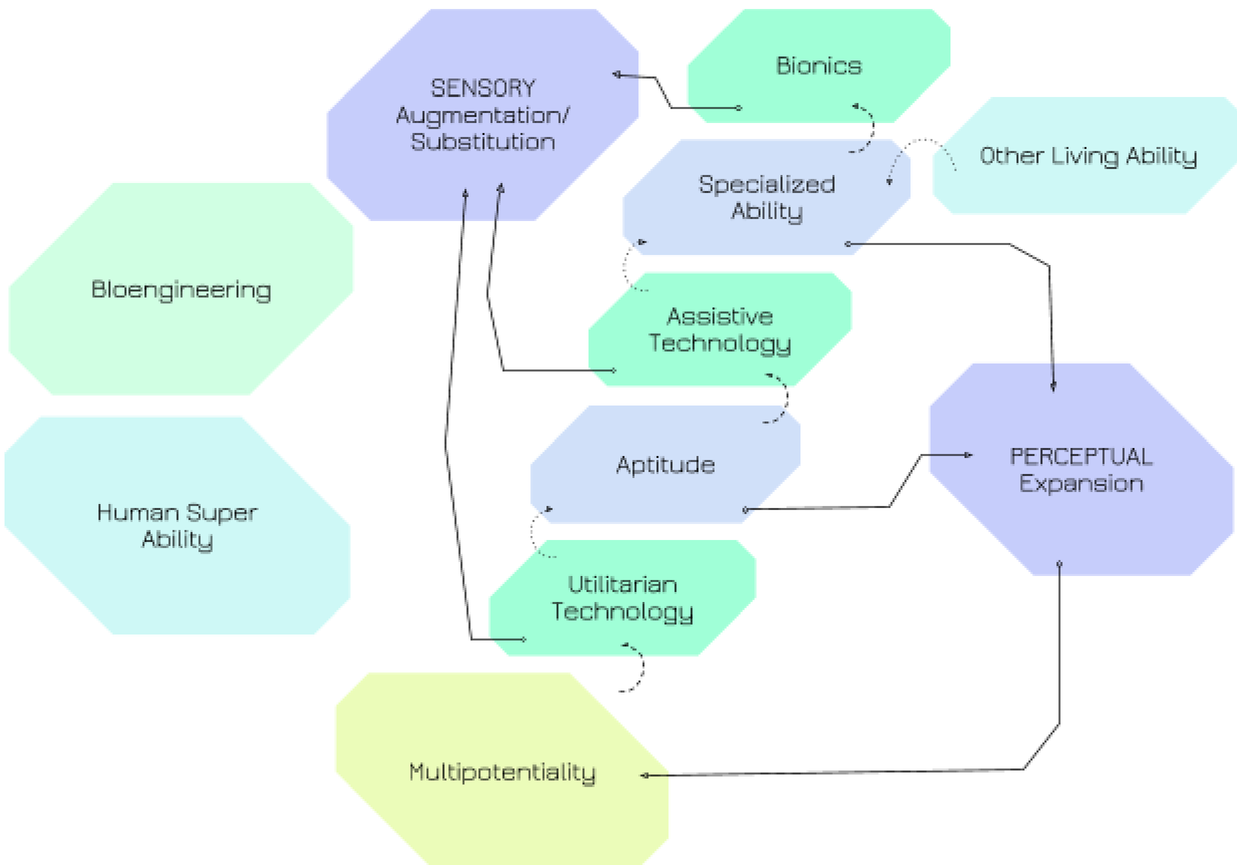

Fig. 2.8 Designing for the Future of Human Evolution

Specialized abilities fall under two realms, one from the compensation of disability and another one, depicted in Fig. 2.8, other living abilities. Echolocation in dolphins and bats, expanded sense of smell in canines, and polarized light and hyperspectral color vision in mantis shrimps are all examples of heightened abilities that can be found in other species. From an engineering perspective, biomimicry is an open book of possibilities for furthering the development of our species through electronic simulations. There are challenges in the transference of biological electric principals to computer processes, as living systems don't operate on logic gates, but rather the regeneration and degradation of electrical channels. Regardless of the operations that will ultimately benefit the ease of the actual engineering of our species, this research only aims to suggest possible adaptations of multipotentiality>> superhuman abilities rather than the genetic process to acquire these.

Sensory expansion and substitution devices arise by mixing and reappropriating on bionics, assistive, and utilitarian technologies that support all levels of human abilities. Perceptual expansion is achieved with these devices by applying instances of specialized ability and including normal aptitude processes during participants' experience to eventually gain multipotentiality.

Chapter 3:

Experiments: Case Studies

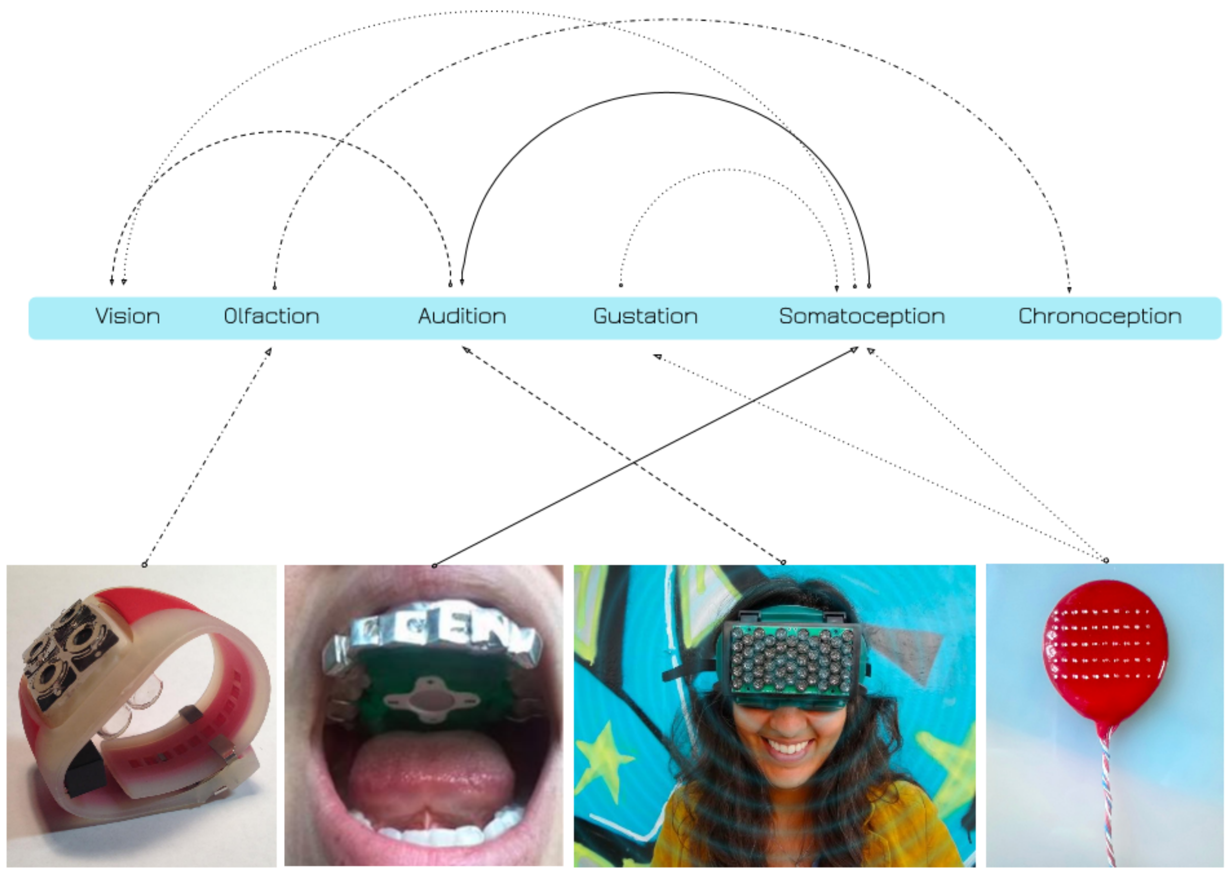

Fig. 3.1 Sensory Mapping of Developed Concepts

The map above shows the currently developed cross-modal computing interfaces (Fig. 3.1). Each of the devices are mapped by the sense they stimulate to the resulting sensory perception. The list of devices in order from left to right are: Scent Rhythm, Play-a-Grill, Echolocation Headphones, and PopMatrix. All of these devices explore the ability of achieving perceptual alterations through brain plasticity and sensory substitution and expansion.

Scent Rhythm triggers the olfactory sense to inform chronoception, as the circadian rhythm is usually informed by photoreceptors. This watch keeps track of the circadian cycle with chemicals that are mixed within the scents at very low doses, since olfaction is a chemoreceptor. The Play-a-Grill utilizes the somatic sense to produce audible sound, this device utilizes sensory expansion. The auditory sense is gaining signals from an alternate avenue surpassing the eardrum. Because both of these senses are mechanoreceptors, they perceive motion, the body can easily mix these inputs. The Echolocation Headphones use sound to inform the conceptual perception of space that lies within the visual cortex. PopMatrix utilizes this same principle of visualizing space to produce images in the mind’s eye.

“ We see with our brains not with our eyes.”- Paul Bach-Y-Rita.

3.1 Pop/Spoon Matrix

Fig. 3.2 PopMatrix

The tongue display unit is an electric visual experience through your tongue. Using sensory substitution, this device trains the user's brain to translate tactile to visual information. It stimulates the visual cortex through the somatic sense by displaying images on your tongue through a series of electrodes. The tongue display units receive visual cues from the computer via a training application created with processing sent through this device worn inside of the mouth by applying electrode vibrotactile stimulation to specifically selected areas of the tongue. Using non-invasive sensory substitution methods, this device facilitates a new port for vision and a discreet addition to the palate of senses.

3.1.1 Precedent

This project is largely inspired and informed by the inventor of tongue display units, Dr. Paul Bach-Y-Rita, whose pioneering work marked the sensory substitution and prosthetics fields. His devices such as the BrainPort are non-invasive and expand on the studies of the elasticity of the mind.

Fig. 3.3 BrainPort and Vestibular Substitution Helmet

The BrainPort is a device that allows users to see images with their tongue (Fig. 3.3). 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.[9] 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 it consisted of a static camera and a bed of electrodes shown on the right of Fig. 3.3. 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.

The BrainPort now consists of a camera, a tongue display unit, and a controller. 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. Which is a much higher resolution than the PopMatrix. The electrical impulses vary from high to low depending on the brightness of the pixel in the static image.[9]

The electrical stimulation does not hurt the tongue; users describe the experience as 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. After enough training and use of the device, users may begin to see images by relating the electric pulses in a spatial arrangement in their visual cortex. Related to gastronomy wine connoisseurs sometimes describing wines with a specific shape.

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.[2] By using this device every morning Schiltz has regained her sense of balance.[57]

The BrainPort was created with the intent of re-establishing sensory disruptions in people, specially those who are blind. This device is completely superficial, which extends its use to non-handicapped 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.[16] 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.[16] 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. 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.

The tongue provides a perfect electrolytic environment which can be a problem with electronics in most cases, but the tongue display takes advantage of this situation to allow electrical flow. This raises the efficiency of the electrical input needed for the device to function. 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.

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. 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 and 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.

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. Thus far there have been no cases of taste or sensitivity loss on the subjects that have been using the prototypes.

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.
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. 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, such as Sterlac's Third Arm.

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. 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. 3.4 The Eye Candy Can [19]

The Eye Candy Can created by Beta Tank shown in Figure 3.4 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.[19] 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. Eyal Burstein, conceptual director of the Beta Tank design lab, actually acquired a prototype of the BrainPort from Wicab. He notes that the effects are very difficult to experience. In order to learn to perceive through this abstract method, it takes a lot of practice.

3.1.2 Experimentation & Functionality

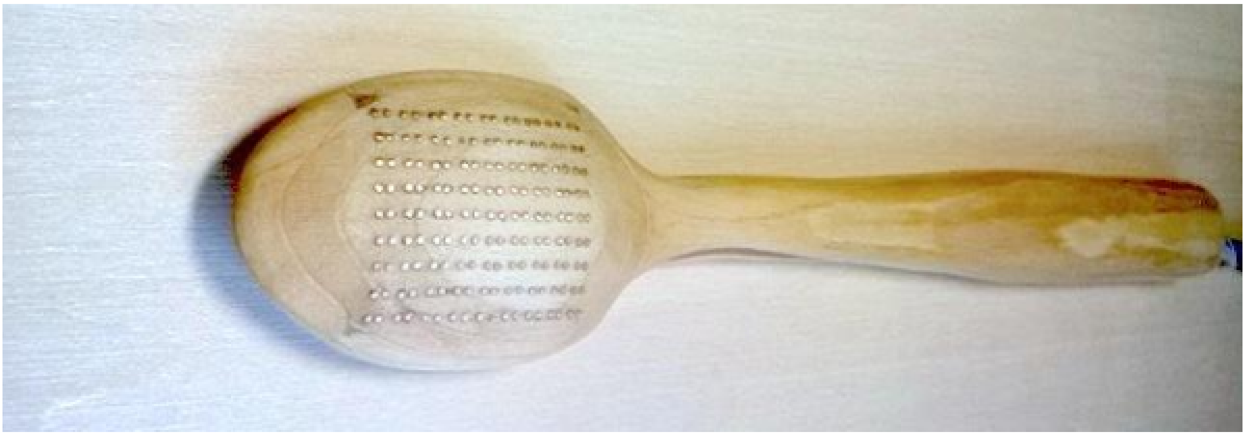

Fig. 3.5 SpoonMatrix

The first iteration of this design was in the original form of the PopMatrix (Fig. 3.2). 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. 3.5) 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 emits light pulses of electricity based on the animations programed for particular dishes. Creating this spoon was extremely difficult as embedding electronics in wood is not as easy as it seems. Like 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.

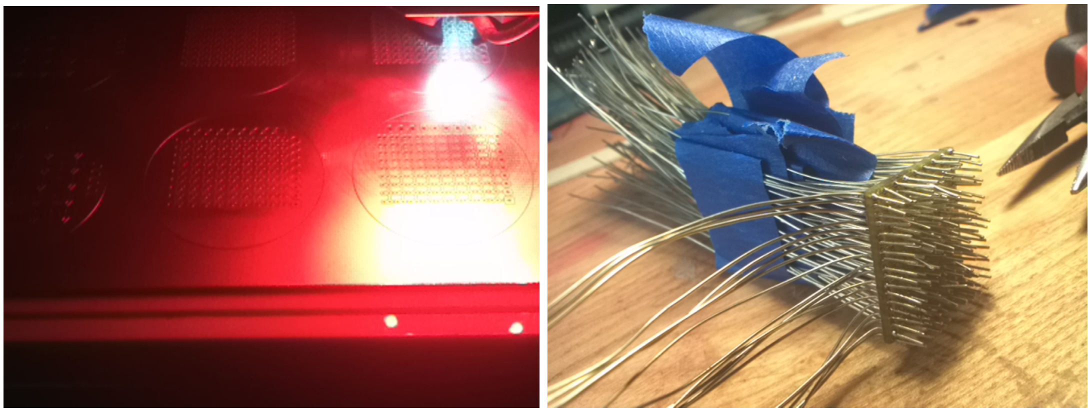

Fig. 3.6 Process PCB Milling and Electrode Soldering Layout

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 at Parsons 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 3.6).

Fig. 3.7 Wiring, Encapsulating, Carving

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. 3.6). 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.

3.1.3 Evaluation of Potential

The PopMatrix and the SpoonMatrix 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. This technology for sighted individuals interpreting this information as visual is not as conclusive as with blind subjects, this has to do with the amount of practice it takes to fully envelope sensory substitution. Another issue found with this technology is the lack of sensitivity that exists in the mid region of the tongue. The interface design of these devices automatically demand movement of the tongue across the electrode matrix, therefore; moving the tip of the tongue across the matrix provide focal somatoception. Perception is experienced by contrast, movements are necessary in order for the brain to make sense of stimuli.

Fig. 3.8 SpoonMatrix

Another form of contrast that makes this crossmodal application more useful is the intermittent effects of the triggered electrodes themselves. This was a solution that was also later observed in conversation with Burstein who experienced the BrainPort. When testing the device the necessity of a pulse to better perceive the location of the pixel in the matrix. As for the SpoonMatrix, there needs 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 preschool 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 part of the research must be conducted along with a gastronomy expert. The tongue display units have spun a series that adds to the palate of the senses, even though 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?

3.2 Play-A-Grill

Fig. 3.9 Play-A-Grill, Future Tech Iteration

Play-A-Grill combines a digital music player with the mouthpiece jewelry known as a grill, which is usually associated with hip hop and rap music genres. Grills are almost always made of precious metal, most notably gold or platinum. They are completely removable, and worn as a retainer. This piece of jewelry presents a perfect opportunity to merge an arbitrary music fashion object and reintroduce it as the music player itself. Because the grill is worn over the teeth, sound can be transmitted using bone conduction hearing instead of outside speakers or headphones.

This concept was inspired by an interactive installation at the Exploratorium Museum in San Francisco called Sound Bite that displayed bone vibration hearing through a rod. A user could slide a straw over a rod, and through biting it and closing her ears, could hear any four different types of music. The clearest sound came from a hip hop music sample. This experience spun an ongoing conversation in my mind about bone conduction and its applications.[52]

3.2.1 Precedent

Bone conduction hearing has been used since the 1880's in commercial products to aid hearing loss, except for instances where the loss occurs due to damage to the auditory nerve. Rhode's Audiophone was the first hearing aid device to be developed utilizing this principle. Also known as the acoustic fan, it was a retractable convex apparatus made of vulcanite, a rare copper, a good reflector of sound.[45] This fan replaced the user's eardrum gathering the sound vibrations surrounding the air and vibrate to their frequency. People could hear by biting the end of the fan, these vibrations would travel from their teeth, to their jaw, and eventually the cochlea.

Cochlear implants are effective bone conduction systems that are directly implanted onto the skull, but less invasive methods have recently emerged such as SoundBite by Sonitus Medical in 2010. This FDA approved device uses a microphone inside the ear canal that transmits the signal to a receiver unit inside of your mouth around the posterior molars.[54]

Artists have also incorporated bone conduction as an avenue for conceptual art, such as the work of collaborators James Auger and Jimmy Loizeau who conceived the idea of Audio Tooth implant in late 2000. Their concept is to create a tooth that contains a receiver to be implanted in a user's mouth that would then replace their cell phone or any long-range receiver. They see it as a form of telepathy that resonates directly in the subject's consciousness.[8]

The music and fashion are the most cyclical of all art and culture based industries. Ideas and aesthetics are constantly recycled, reappearing decades later. Both of these cultural expressions are seamlessly embedded in our daily lives, and they are venues to our personal identity.[50] Hip Hop is a flexible and powerful tool of communication, given its rebellious spirit, materialistic values and passion. From the late 70's to mid 1980's Hip Hop style was about promoting self-identity. Wearing jackets and hoodies with their name drawn on the back, painted baseball caps worn sideways, and enough gold chains to buy an international flight. Hip Hop always glorified the display of wealth.[21]

Fashy expensive jewelry has always been the preferred Hip Hop fashion statement. Referred to as Bling-Bling; gold chains, diamond watches, pendants, and especially mouth jewelry pieces are Hip Hop's crown jewels and an explicit display of wealth and power- biting the wealth. The grill, also known as a front, is the most iconic Bling. Removable grills became fashionable in the 1980's by Edddie Plein, owner of Eddie's Gold Teeth in New York City, who fitted famous Flava Flav. Then later once the millennium hit Dirty South rappers spun the fashion back into a national epidemic of diamond teeth.[49] In Hip Hop slang, diamonds are referred to as ice. Rap star Nelly dedicated an entire song to grills and their fashion sense in collaboration with other rap artists, Gipp, Ali, and Paul Wall the owner of a business manufacturing grills from $20 - $30,000 in value. Some of the verses of their song Grillz say:

"Got 30 down at the bottom, 30 mo at the top
All invisible set in little ice cube blocks
If I could call it a drink, call it a smile on da rocks…"

-Nelly [33]

"I got my mouth lookin somethin like a disco ball
I got da diamonds and da ice all hand set
I might cause a cold front if I take a deep breath
My teeth gleaming like I'm chewin on aluminum foil…
Piece simply symbolize success
I got da wrist wear and neck wear dats captivatin
But it's my smile dats got these on-lookers spectatin
My mouth piece simply certified a total package
Open up my mouth and you see mo carrots than a salad
My teeth are mind blowin givin everybody chillz
Call me George Foreman cuz I'm sellin everybody grillz."

-Paul Wall [33]

In the history of the World, teeth decoration goes deeply into our histories. The oldest record of embellishing teeth is a skull found in Mesoamerica from 2500 years ago. The skull has gems set on the teeth by carefully drilling holes that did not penetrated the tooth pulp, showing the high skills of ancient dentists.[6]

Fig. 3.10 Play-A-Grill: Original "ICEN"

3.2.3 Experimentation & Functionality

The process of creating the Play-A-Grill was done in two phases of prototyping. The original was created in 2011 and exhibited in NIME in 2012, which gained a lot of social traction and spun the next iteration.[13] The second prototype was custom designed for the host of Future Tech Discovery Channel Canada, Lucas Cochran. This section breaks down the electronic and aesthetic components of both functional prototypes of the Play-A-Grill.

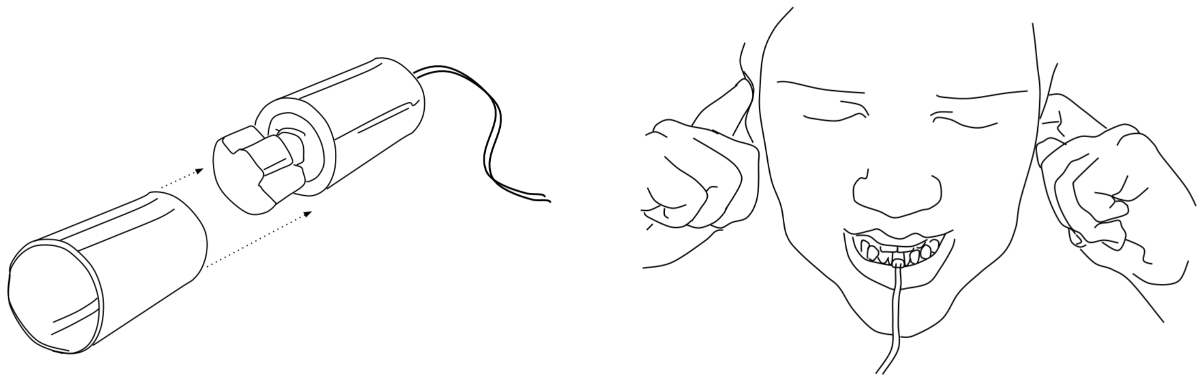

Fig. 3.11 Motor Bone Conduction Test Interaction Diagram

In order to test bone conduction I used a small vibration motor and connected the leads to a headphone jack cable. Then plugged it into an mp3 player and the results were positive (Fig. 3.11). This alpha stage prototype was successful and the tester was able to hear the sound through his teeth. The volume of the device must be set to high in order for the sound to be perceivable, it is more audible with higher amplification. If the music is amplified enough the concave shape of the palate make the sound vibrations resonate throughout the mouth resulting in a speaker perceivable to those around you through normal airborne audition. The idea of vibrating teeth sounds dangerous, and like grills, it is not recommended to wear the Play-A-Grill for extended periods of time. Also, it is better to use less sound amplification, and instead covering the ears to better hear the sound from bone conduction, making it a more personal and private experience.

The vibrations are barely perceivable by touch, they are faint and not strong enough to hurt your teeth. The motor translates the electric sound waves into mechanical movements. Your sense of hearing is a mechanoreceptor, which can translate movement as sound, so long as the wave is in the audible frequency of 20Hz- 20KHz. Higher frequencies are easier to perceive than lower frequencies because of their speed. In the diagram below you can see the sound traveling from the molar to the jaw, and then resonating the areas that are close to the inner ear.

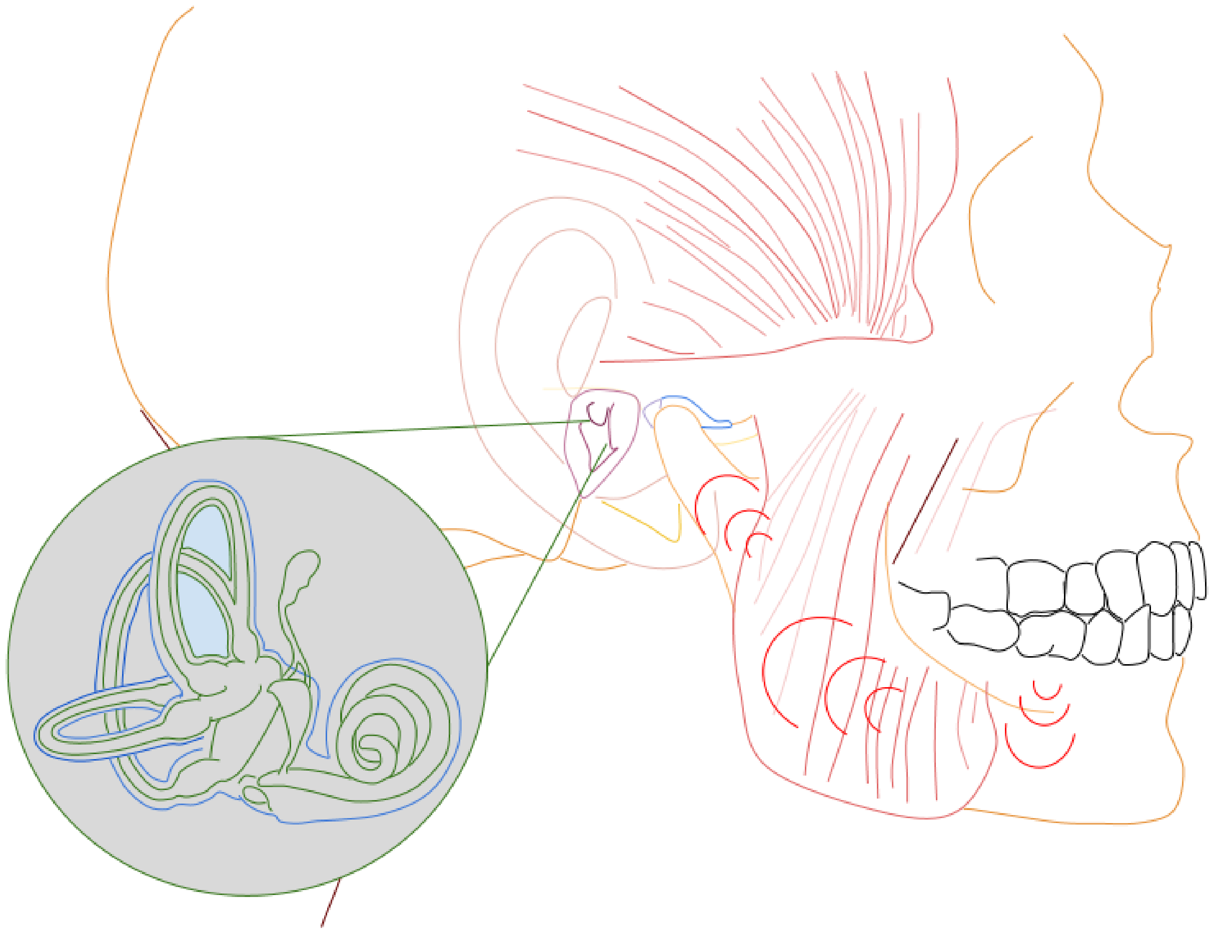

Fig. 3.12 Bone Conduction Hearing Diagram

The gray circle depicts the whole inner ear system. There are three ossicles, also referred to as the *hammer*, *anvil*, and *stirrup.* These little bones translate the sound coming from the eardrum and vibrate the cochlear fluid. The cochlea is the spiral bone filled with fluid and its vibration is then translated into neural impulses that are translated into what we perceive as sound in the brain.

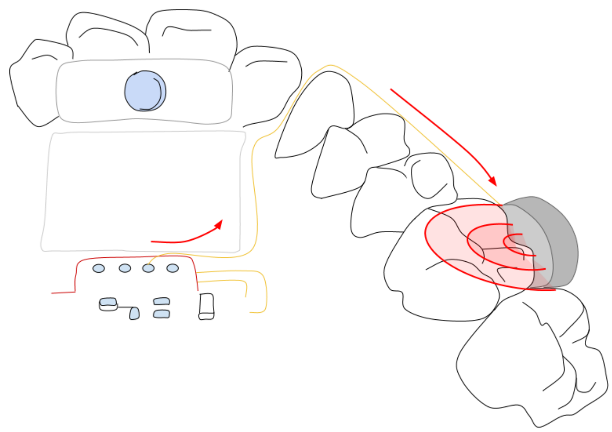

Fig. 3.13 Play-A-Grill: Sound Traveling Diagram

Bone conduction works by vibrating the bones to the frequency of sound, In this image above you can see the action illustrated. The sound travels through a cable to the transducer, whether this is a motor, piezo buzzer, or conventional speaker. The magnet in a speaker functions in the same way as the motor. It vibrates to the sonic frequencies passed to it and it moves a membrane that pushes air back and forth. In that case sound is travelling through air, which we can pick up with our eardrums. In the case of the motor it vibrates slightly elapsing the oscillations with small on and off sequences. Because the sound doesn't need to travel through air, it does not need a membrane to push the sound. Instead it vibrates the molars directly, and any surface around it.

Both prototypes begin by making a mold of the mouth with alginate, to create a positive plaster casting to be used as a design guide for the device. This material is used by dentists to make bite molds for diagnosis and other orthodontic purposes. The material sets very fast, and because it is made of algae it dries very quickly, which means that the plaster casting needs to be poured immediately. Once the cast has set overnight it is ready to be used as a guide for the grill model.

The most challenging aspect in designing this interface is the negotiation of space in such a delicate area of the body. Designing an interface for electronic components inside of the wet and highly in demand mouth has many challenges. The tongue sits in the mouth in rest position, which allows for certain space at the roof of the mouth to be negotiated. This interface though cannot be bulky to allow comfortable space for the tongue, and it ~~should~~ especially must be away from the posterior molars. The soft palate begins after the whole length of the teeth; if the device is further out than the molars, the device will cause the user to gag. Gagging is about the worst user interface experience that can happen.

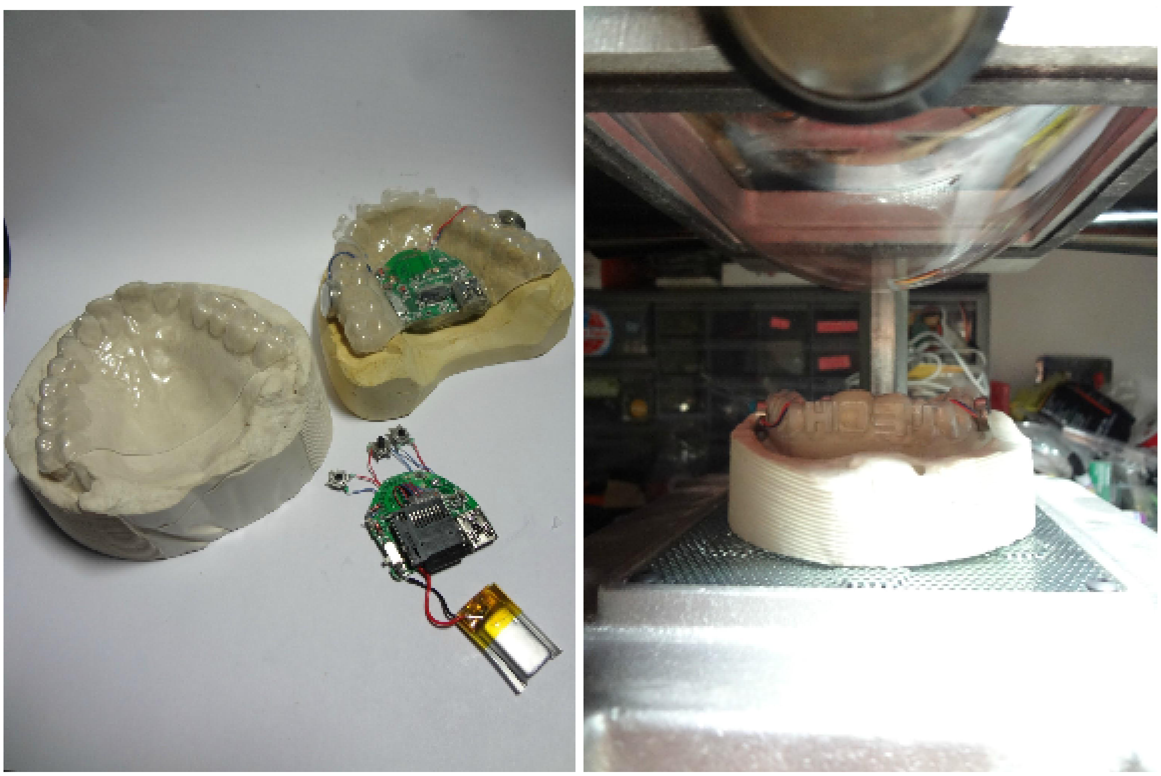

Fig. 3.14 (left) Electronic Components First Iteration Layout, (right) Vacuum Forming Layer

How thick can this device be? Would it be better to have more open space close to the top anterior teeth, or at the roof of the mouth? One solution, can be found by an experiment I created using gum. In this experiment the participants are given as much gum as they can possibly fit on the roof of their mouth and still be able to talk. Then asking them to spit it out, with as little disturbance to the gum mold as possible. Images from these results can be compared in order to measure the approximate mean of thickness for a tolerable and comfortable mouth interface. This experiment can be very useful also to record tongue movements in the mouth. Perhaps the best button/ toggle interface is as flexible as the tongue itself. This gum playtesting could be an exciting, new approach to tongue interface research, yet to be deployed. It could provide a mean of approximate measures of mouth positions and interaction methods. This test reveals how think about their tongues, how they position them when they are resting, and which sounds are more difficult to create with something on the roof of the mouth.

The circuit must not be exposed at all to the actual environment of the mouth, otherwise it must be waterproofed. The surface of the device must be smooth and comfortable for the tongue in its rest position. The original model of the grill was made with thermo molded hot glue, this was a fast way to introduce a material that would protect the circuit from the mouth environment and viceversa. This solution was practically functional, but it made the interface bulky and difficult to wear. The material is also not made for being inside of the mouth, so there are safety precautions. This was the main aspect that changed in the second model. The enclosure for the Future Tech Grill will be created by using professional dental technology to ensure the safety of the material for this wet and delicate area. It was created with a special material used for whitening trays that will protect the teeth and the soft tissue of the palate and the tongue, as well as the electronics embedded between two molded sheets of this material. This material allows the enclosure to be compact and transparent protecting the electronics from saliva, and protecting the body from the circuit. These devices are custom fit like most grillz. The plastic allows the device to grip firmly to the teeth of the user.

This is done with a vacuum thermoforming technique. The plaster cast model is placed onto the bottom plate of the vacuum forming machine and the material is placed on a frame that holds it in place while it is heated to form a bubble. Once the material is plastic enough it is pressed onto the plaster cast and suctioned tightly on to the form. This process was very different from molding hot glue, especially because it changed the layout design. The first layer of material is flush to the mouth, the electronics are embedded in the second layer, and finally the third layer seals the electronics in place as tightly and efficiently as possible. This material allows the enclosure to be compact and transparent protecting the electronics from saliva, and protecting the body from the circuit. These devices are custom fit like most grillz. The plastic allows the device to grip firmly to the teeth of the user.

Other problems are to do with aesthetics, eg. should the color of the enclosure be clear or matted in a different color? Should the jewelry mouthpiece be precious metals or a different material? For the first iteration, I used metal casting grade wax. I made the wax wrap around the 4 posterior top teeth and attached the letters spelling ICEN over the wrap. I chose ICEN because “ice” is a play on the slang term for diamonds in Hip Hop culture, and it is also phonetic play on my name. Also resonating on the early years of Hip Hop when promoting one's name was more important than sporting brand names. Once the wax model was finished, Quality Mold Making cast the model in silver. When I picked up the cast the first thing I did was put it in my mouth to see how it fit. The jeweler yelled at me "No don't do that! I clean it in cyanide after it is cast." I am very glad I did this in front of him and not on my way back home on the train.

Aesthetically this was an effective decision, because grills are inherently made to display wealth and precious metals are more true to the artifact. If the device's enclosure is clear plastic, its transparency may have negative effects on the user. Seeing the battery and the electronics exposed might present the user with further reflection about this sensitive area, and whether they will expose themselves to such a device. In order to 3d print the silver mouthpiece, it will cost twice or three times as much than fabricating it by hand. The font and design could be slicker imaged directly from computer numerical control, but the cost could outweigh the benefits.

Fig. 3.15 Lucas Wearing the Play-A-Grill (left), Discovery Channel Film Crew (right)

For the second iteration the grill spells "TECH" because it was commissioned by the Future Tech host of Daily planet. This decision was made in order to stay true to the identity of grills and their customization principles. Laser cut plexiglass letters replaced the hand-cast silver model in order to resonate with the clear plastic and also to provide a more legible font that is computer generated and precision-cut. This also drove down the cost significantly, which deters the wealth display concept inherent in the grills and rather embraces the electronic aesthetics.

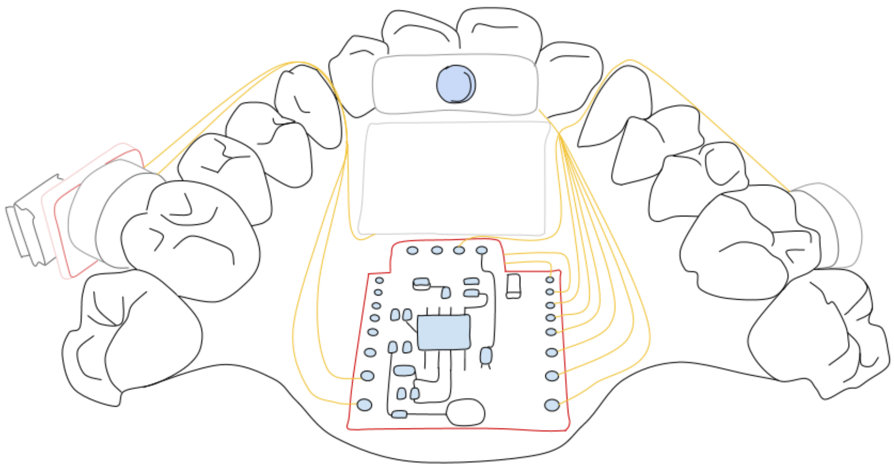

Fig. 3.16 Play-A-Grill: Electronics Layout

The circuit has a few parts an mp3 player that controls your music, a usb connector which allows you to upload new music and charge the lithium battery, sometimes referred to as a LiPo cell. It has a tongue controller that allows you to manage the music flow, whether you want to pause/ play, forward or revert to the next song. The circular pieces on the sides of the molar are motors that transduce the frequency of the sound through bone conduction. The original Play-A-Grill had one motor instead, by adding the second motor the sound is distributed more evenly among the jaw. Both circuits have an Op Amp integrated that amplify the signal to its optimum volume. The LiPo cell can be a bit dangerous, and this is why the circuit is completely enclosed and waterproof protecting your mouth from contact with the circuit. It is advised that you take good care of this device, that you don't drink or eat while wearing it, at least abstain from any hot foods/drinks.

Hacking an existing digital music player that has a tactile interface that does not require vision to manipulate, this way the tongue can control it. Finding the right music player small enough to fit in the mouth of a user is the first and most important criteria. Secondly it needs to have button controllers apt for translating their actions for tongue to use. Thirdly it must be inexpensive, since it will be subjected to hackery and surgery, and I will most likely use more than one. Indeed, I used four. Both digital mp3 player used were a knock-off brand copying an older version of the Ipod Shuffle, the first was a bit larger than the second. This was a perfect device because it met the tactile controls for the tongue, the size requirements, and since it was a knock-off brand, inexpensive. The first step to the surgery of the player is to break the enclosure, then to de-solder the headphone input and soldering a motor. This is an easy hack and there was not much to it. I found that the quality of the sound was too faint, and in order to solve this problem I added an Op Amp breakout board to amplify the vibrations of the motor. I connected the two leads of the motor to the amp and then to the output of the device, and two other leads that shared the power supply of the amp and the device. The first time doing this operation, I soldered off the power connections on the circuit board and had to start fresh with a new mp3 player. These kind of mistakes happen less often with practice. Once the operation was repeated and successfully completed, I organized all the components and the grill together on the mouth mold.

Fig. 3.17 Play-A-Grill: Original Controller Mechanism

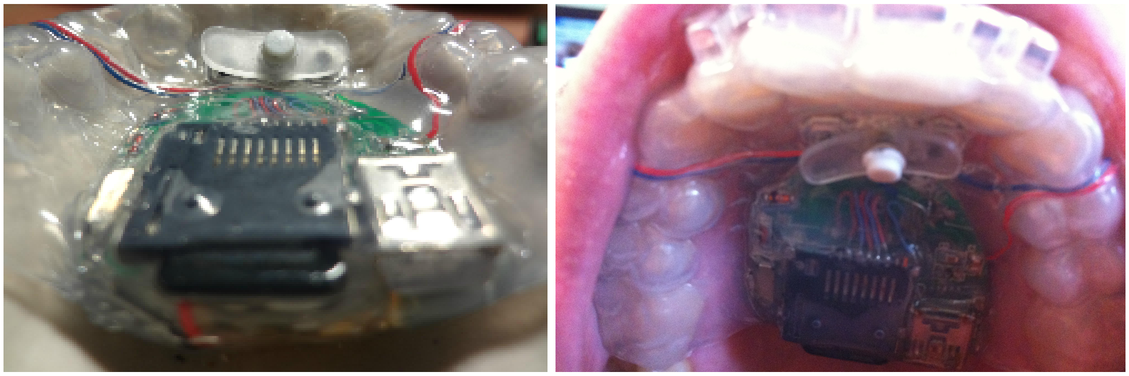

Fig. 3.18 Play-A-Grill: Future Tech Layout, New Controller Interface

The original interface for the Play-A-Grill appropriated the button functions that were designed on to the hacked mp3 player. This mechanism is not very effective for the tongue because it is too hard to press. Also, the buttons placement in the roof of the mouth was an awkward position for the tongue to flex. It was successful in that it clearly showed the concept in one image, since most people are familiar with this navigation interface for small digital music players. The second interface was redesigned to better fit the function, placement, and condition for the tongue as a controlling appendix. Figure 3.16 depicts the basic layout of the circuit, starting at the top is a lever button that has 3 function capabilities <<previous ||pause & play> forward >>. This lever button was created specifically for tongue interaction, using similar interactions of the lever switch, this mechanical interface is concave, soft and an appropriate size for tongue interaction.

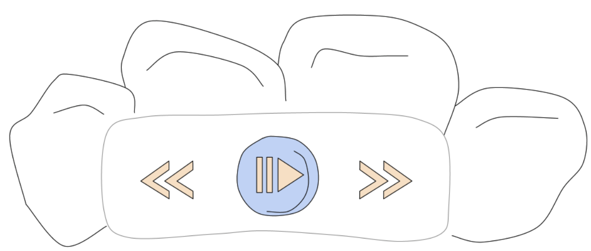

Fig 3.19 Play-A-Grill: Button Functionality

The tongue control allows the user to pause or play the music with one toggle at the same button. In order to toggle the forward and previous command switches, I devised a simple lever switch that follows the same spatial principles as common music interfaces. By pressing the lever on the right or on the left the user can sort through the database and choose their song.The tongue is a bit different in strength and consistency than a finger. Because this organ is softer and larger it requires new solutions for controller interactions. The button in the center is easier to press than the button on the sides, this is because your tongue can form a firm point towards the center, but once you directed to a certain direction it loses strength at the tip using a lot the muscle power to change its direction. The lever allows the tongue to have more surface area to activate, and because of the curve of the lever it requires a lot less strength to press.

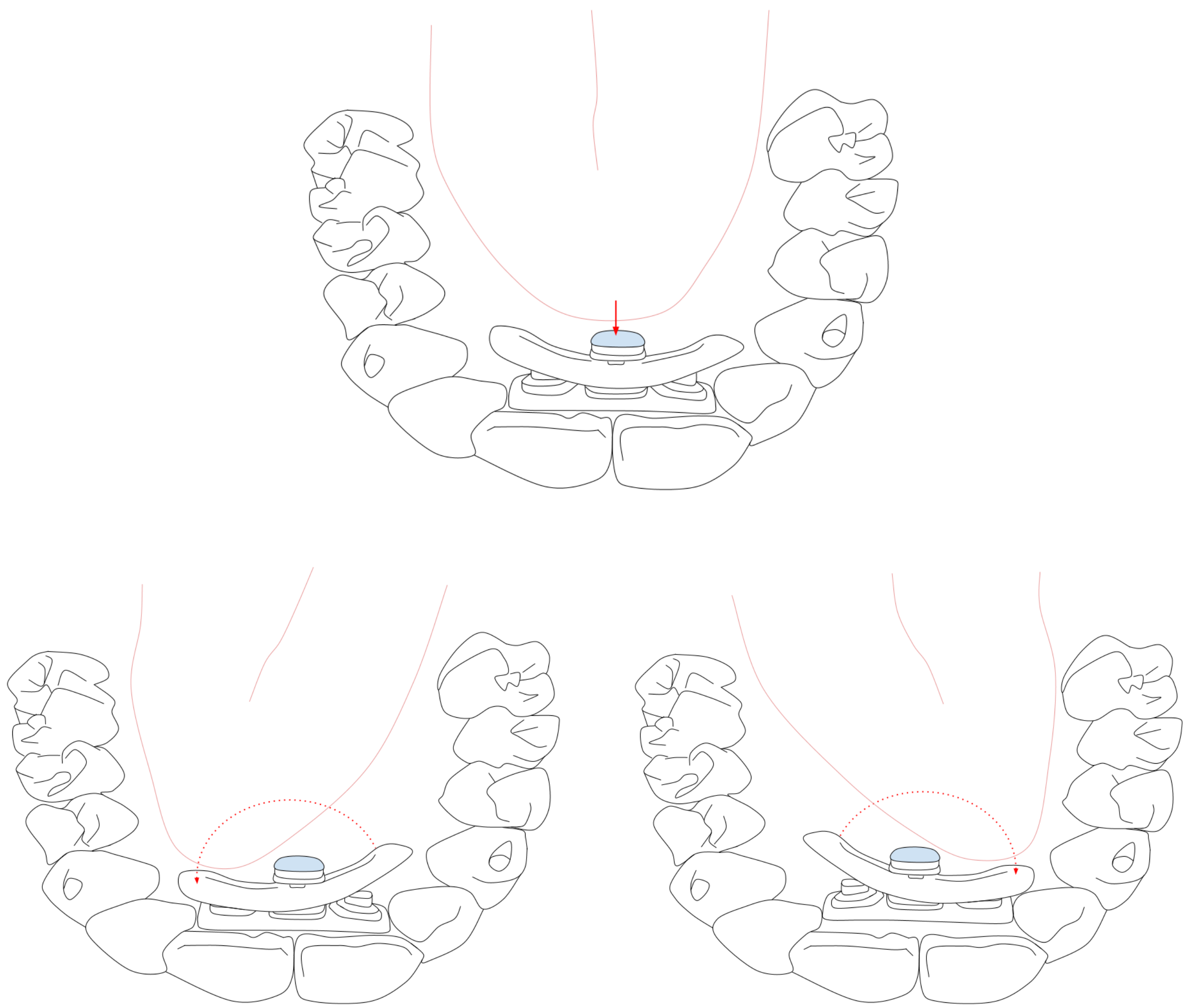

Fig 3.20 Play-A-Grill: Lever Button Interaction

Tongue interaction and controllers are a large part of this research, This field is relatively scarce as there are not many uses for it today. The largest function for tongue controllers is to assist paraplegics or people with motor disabilities. Can you imagine new uses for the development of this technology? Would you drive your car with your tongue, or dial a phone number?

3.2.3 Evaluation of Potential

The Play-A-Grill is an attempt to provide an unusual sonic display experience and new interface for tactile/visual tongue-digit control panel. It is a device that merges the arbitrary music fashion object and empowers its function by making it the music player itself. This removable jewelry mouthpiece is the epitome of hip hop music fashion. Combining this culturally iconic Hip Hop device with the physiological phenomena of bone conduction produced a strong reaction from the public. It was awarded Project of the Month in November of 2012 by Popular Science, and mentioned worldwide as a novel invention.[40] [5] Without a doubt the contrast of Hip Hop and science colliding becomes a spectacle of social occurrence. There have been many inquiries for collaboration to further develop this project. Chris Mann, has contacted me to create a new prototype for him with no rap identity and rather a simple usable tool. He wants a candy that can speak, practically adopting the style of the PopMatrix. His research comes from modalities of speech and poetry and teaches at the New School in the Media Studies program. Other inquiries have been centered around bone conduction technology for the deaf including, The National Technical Institute for the Deaf in Rochester and individuals from a deaf community in Spain, and Toronto Canada. If their nervous auditory system is intact, deaf people can hear if the vibrations are sent to the cochlea. This technology has proven to be useful with cochlear implants, working with the same principle of bone conduction. There is no clarified direction or projects with these contacts, but rather a request from them of possible interactions. While there is still much to be done to progress this research as a whole, the main goal is to connect the dots of interaction, especially in alternative displays and mechanics of control.

The idea of a digital sound device inside of the mouth has many potential forms, eg. audio recorders to serve as a short memory device, allowing the user to record their conversations. It could be modeled after a stick of gum, and you can stick your outside thoughts to it. Another exciting application could be to embed a cellphone bluetooth device. Applying this technology to braces could prove effective to improve their lousy experience by giving them access to music at any time, even at school and no one would ever know.

The battery is the greater issue behind this idea becoming a marketable product, (no surprise here). The the potential dangers of wearing a LiPo cell battery inside the mouth, need to be revised by a team of engineers to include the safety and general protocols for interfacing the body with electricity. Understanding the health standards and safety precautions taken in the Biomedical Electronics field will inform the technical functionality of these prototypes. The next step will be to initiate conversations with professionals in the Biomedical Engineering and Human Computer Interaction fields with the impetus to forge relationships and possibly collaborate, or simply inform the design and feasibility of commercial applications for these technologies.

Fig. 3.21 Play-A-Grill: User Diagram

3.3 Echolocation Headphones

Fig. 3.22 Echolocation Headphones, User: Galina Rybatsky

The Echolocation Headphones are a new application for parametric sound that aids auditory spatial location. This study emphasizes the augmentation of the auditory sense by enhancing our current ability to process sound through providing a focal point to audition, similar to a visual focal point. Currently, human echolocation is being explored by some members of the blind community who have reached an increased understanding of sound and spatial relationships. This tool was designed for both blind and sighted individuals in mind. This technology is beneficial for some kinds of blindness because it could provided a focused acoustic beam for spatial mapping, unlike omnidirectional mouth or cane clicks. It is also a training apparatus that allows sighted people to learn how to navigate space through sound. The Echolocation Headphones' sensory-mixing functionality is to translate auditory processes to visuospatial skills.

3.3.1 Precedent

The perception of allocentric space is a visuospatial skill that includes navigation, depth, distance, mental imagery, and construction. These functions happen in the parietal cortex at the highest level of visual cognitive processes.[11] An important function of the parietal lobe is to integrate sensory information, such as the manipulation of objects.[10] It includes the somatosensory cortex and the dorsal stream of the visual cortex. The dorsal stream is referred to as the "where" or the visuospatial processing, and the ventral stream as the "how", such as the vision for action or imagination. [23] [31] Acoustics can also inform the visuospatial processes, because of the sound waves' sensed timed arrival, processed by parietal cortex. Accounting for the speed at which sound reaches your ears, can result in realistic effects generated in sound playback. Professor Edgar Choueiri from Princeton University founded the 3D3A Lab to study fundamental aspects of spatial hearing in humans.[1] The lab has developed a technique to filter sound playback with a three dimensional effect, making it possible to simulate the a fly circling your head with normal speakers, without headphones. He explains that our brains only require a few cues for locating the source of sound. The first being, the time that it takes for sound to reach one ear versus the other, and the difference between the two time intervals. The second cue is the level differential of the sound arriving at the two ears. In order to achieve this same principle with two frontal left and right speakers the sound must be recorded with two microphones equally spaced to the position of the ears on a human head. Dr. Choueiri has developed filtering techniques for 3D-audio playback that cancel the crosstalk between two speakers. This prevents the cues from the left speaker to arrive at the right ear and viceversa. These filters are effective in providing the brain with the right information for processing spatial audition from an artificial playback environment with no headphones required.[59]

Fig. 3.23 Daniel Kish: Echolocation Methods for Spatial Interpretation

This same principle of audio spatial attention used to recreate 3D-audio playback simulations can be applied for echolocation. Daniel Kish is the president of the World Access for the Blind an organization that helps individuals echolocate; their motto being “Our vision is Sound”.[14] He describes himself as the real batman, and has been echolocating since he was a year old.[41] Kish has mastered echolocation through the interpretation of mouth clicks to gain understanding of his spatial surroundings. In some blind individuals, the brain has appropriated functions of the visual cortex to have a heightened sensitivity for sound in spatial processing. The dissemination of this technique has helped hundreds of blind people to regain “freedom”, as he describes it.[41] People who are using this technique can navigate space flawlessly, ride bikes, skateboards, and ice skate, including the ability to locate buildings hundreds of yards away with a single loud clap. The clicking is a language, that asks the environment- “where are you?” with mouth sounds, cane tapings, card clips on bicycle wheels.[14] These clicking sound waves sent to the environment return imprints of their physical encounters, as if taking a sonic mold of space.

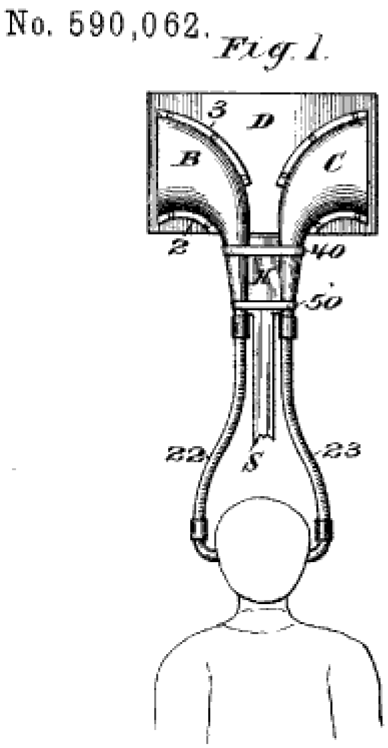

Fig. 3.25 Topophone (left) [41]   WWII Military Bomber Detector (right).

The Topophone was invented by David Porter Heap in the United States in 1880.[38] Its purpose was to amplify the sensation of particular sounds. The wearable parabolas he created could be tuned to the pitch of the sound to be detected. His device was later adopted by the army in order to serve as a defense mechanism to detect enemy combatants.[39]] This device became particularly useful once the airplane was invented, as it aided the location of airborne bombers. During the second World War in the 1940s, the Allies created radar technology giving them the benefit and great advantage of spotting enemy planes over hundreds of miles. Radar utilizes the same principle of detecting the imprint of reflected sound by measuring the resonance of a semiconductor crystal, or a rectifier.[43] Without radar technology other WWII combatants had to rely on their own sense of hearing with auditory extensions such as the topophone and acoustic mirrors.

3.3.2 Experimentation & Functionality

The first instance of this idea surged while I was experimenting with a parametric speaker in an open backyard of a mountainous area in Los Angeles. I held the speaker to my ear, closed my eyes, and began to scan the environment. To my surprise, the imprint of my spatial surroundings reflected in the returning sound was perceivably accurate by at least 200 feet. This unusual idea of hold the speaker beaming away from my ear was inspired by my then recently acquired knowledge of Daniel Kish's experience with echolocation. It seemed to me that achieving his level of sound mapping mastery could only be acquired based on rigorous practice. People who are not used to perceiving spatial information through sound would normally have a hard time differentiating the surfaces of their surroundings 200 feet away based on sound alone, but by utilizing a parametric speaker the threshold for auditory spatial location lowers and its effect is more immediate.

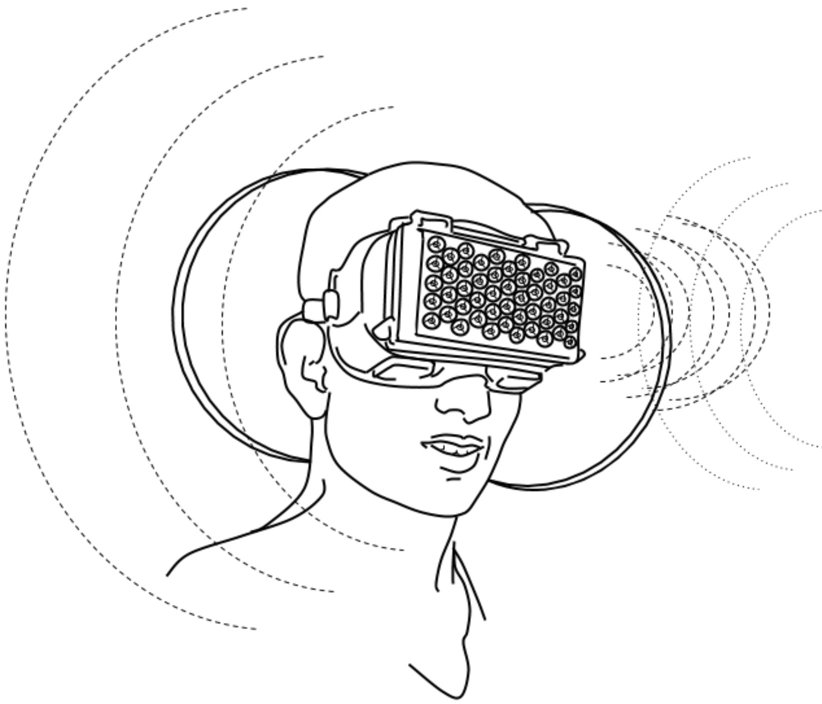

Fig. 3.26 Echolocation Headphones: Sound Interaction Diagram

A parametric speaker uses a focused acoustic beam, and it does this by sending intermittent high frequency sound waves. One of the waves remains at a constant ultrasonic signature and the other is equal, except it also includes the sonic frequency of the sound being played through it. For example one ultrasonic wave is 30 KHz, the other is 30+ KHz (plus the added audible sound wave). When the waves reflect from a surface they collide and their equal frequencies are subtracted to produce a differential the audible sound, which is the added sound wave. This added soundwave can come from any device that plays music and has a headphone jack, such as music from an mp3 player. This is similar to the filtering that was being done by the 3D3A Lab in Princeton. Spatial behavior of sound waves can be calculated and affected programmatically by accounting for the time intervals between sonic signatures.

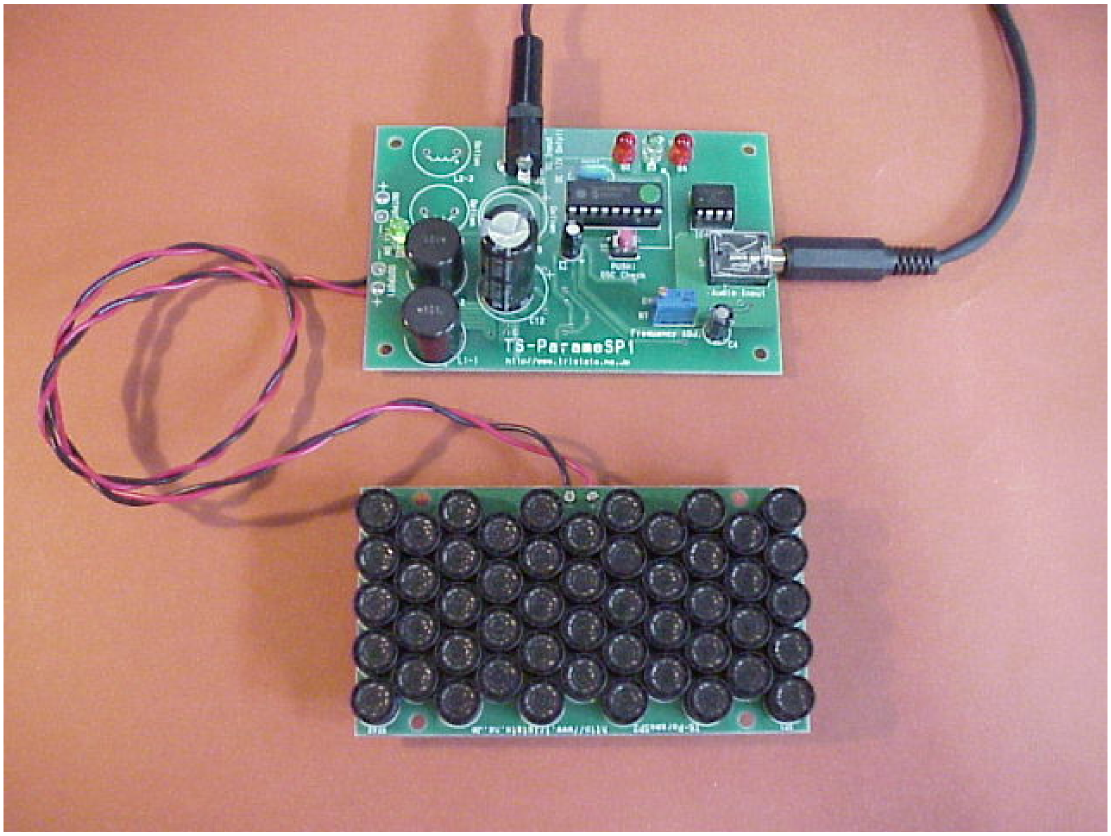

Fig. 3.27 TriState Parametric Speaker [56]

The parametric speaker utilized in this project was created by a Japanese company called TriState. The availability of these speakers is limited, and therefore very difficult to attain. There are a few other parametric speakers such as the SoundLazer, a successfully funded Kickstarter project, created by Richard Haberkern.[51] The original and more sophisticated version of parametric speakers is the Audio Spotlight by Holosonics, invented in the late 1990's by Joseph Pompei.[24] Naturally these speakers are of the highest quality in parametric sound, and their prices reflect their sophistication. TriState offered the most economical and attainable speaker of this sort at the market at the time.[56]

The focus was directed towards the functionality of the device rather than the technical recreation of a parametric speaker. Once the speaker arrived from its long journey from Japan, I realized that I purchased the wrong kit. Instead of buying the whole driving circuit, a supplementary speaker arrived without the microcontroller. This set me back two weeks, in the prototyping phase of this project. While waiting for the completed circuit to arrive, I began thinking about the integration design of the speaker as a wearable echolocation device. One idea involved the ability to control the rotation of speakers, similar to the dexterity and movement that animals such as dogs and cats possess on their ears. Should there be two speakers in order to inform both ears independently from each other?

Thinking about a binaural hearing spun ideas of having two speakers, but while testing it became apparent that the sole speaker and the latency between the ears was crucial for the nature of echolocation- seeing through sound. It occurred to me that members of the blind community wear dark glasses. In the book “Design Meets Disability”, Graham Pullin, describes glasses as a type of assistive technology.[42] Appropriating the sensory function of glasses to be the placeholder for headphones seemed like the perfect opportunity for aiding audition. The priority of this interface is to place the sense of hearing at the center of the design.

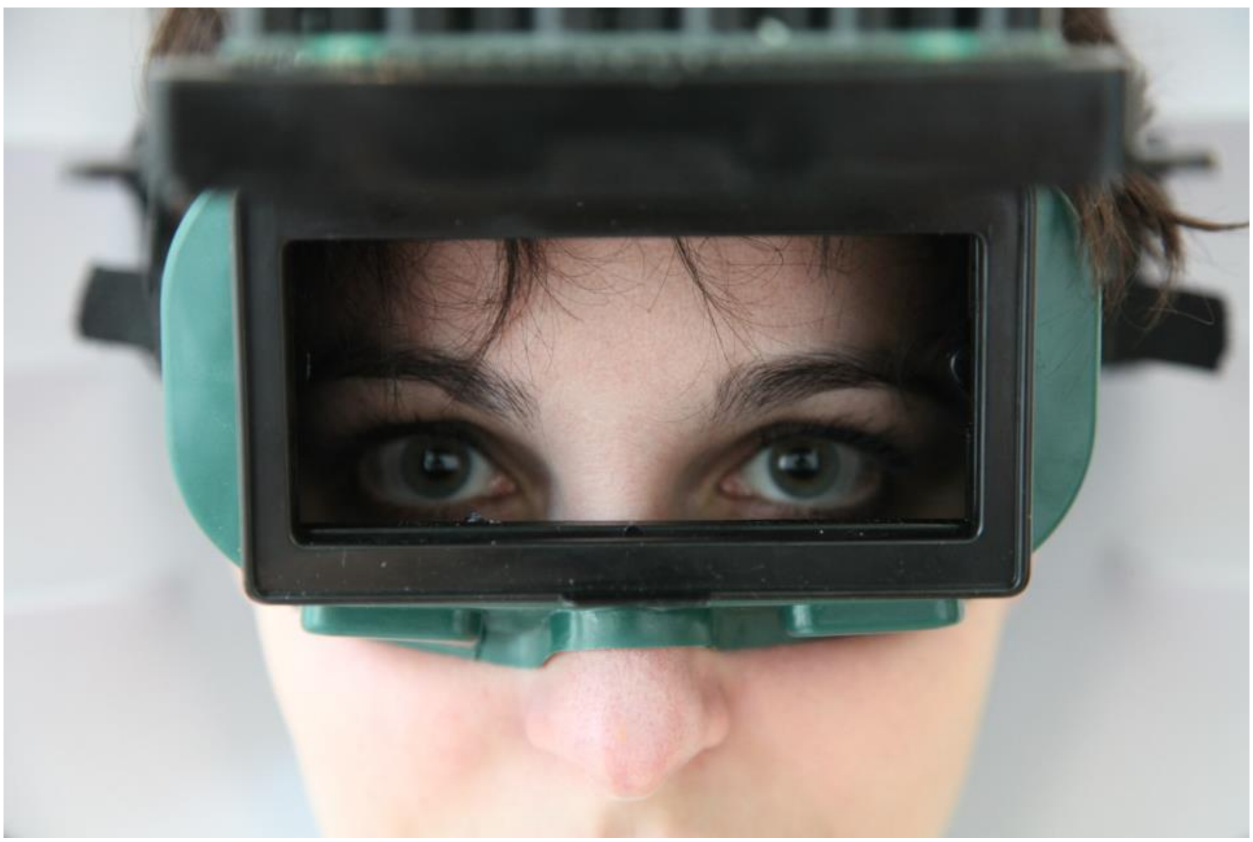

Fig 3.28 Echolocation Headphones: Goggle Functionality

Welding goggles are designed to provide as much protection as possible from the harsh light that is produced when fusing metal. They are designed to introduce as little light as possible, which make them attractive for the acoustic-spatial training necessary for sighted subjects. The glasses are not entirely depriving the sense of sight purposefully, so that sighted users can get accustomed to mapping spatial information from sight to hearing. Another useful aspect of the inherent design of these welding goggles, is the ability to open and close the obstructing panel holding the speaker.

After incorporating the parametric speaker from TriState and the welding goggles, the next step was to add a 12V 1 Amp battery and charger circuit. This was the most important upgrade to the design because it allowed the user to have the freedom to explore their surroundings without being limited by the electrical connections to the wall. In order to create an enclosure for the electronics of the parametric speaker and the added battery charger circuit, I decided to incorporate concave resonator plates inspired by the topophone. This was a great solution for integrating the electronics and the goggles, and the challenge shifted to finding the right plates. I searched for aluminum bowls and other concave surfaces that could amplify the resonating signals, and found the oddest solution, the rotary top of a trash can. This solution is an example of the playful visualizing mechanics that occur in the ventral stream. Stripping objects from their function and adopting their form for other uses also functions with a similar process of visuospatial mapping.

Fig. 3.29 Echolocation Headphones: Profile View

Fig. 3.30 Echolocation Headphones: Back View

In order to add a compartment for the electronic components, I created a vacuum forming machine. This technique would allow me to make a custom shape to fit the head plates. At first, I wanted to create a sort of helmet that kept the electronics on top of the head. By playing with the pieces of the trash can lid and testing different forms of integration, it became clear that adding the compartment to the back of the head was a safer and more aesthetically cohesive design choice. Once the compartment shape was finalized it was vacuumed formed on to the amplifying parabola. Then, both forms were detailed with chrome trim originally used for car doors. This physical extension to the ears had a sonic amplification effect and helped the recollection of sound.

3.3.3 Evaluation of Potential

This case study also stimulates the mapping function of the visual cortex while aggregating spatial information, similar to the spatial processing of tactile maps on the tongue explored in PopMatrix experiment. The tests displaying the feasibility of sonic visuo-spatial location through the Echolocation Headphones as a training device for sighted individuals, are positive and more immediate than the electric pulses on the tongue. I have found a new application for the parametric speaker as a tool for echolocation that appropriates its original function by focusing the experience outward as a wearable device. Usually these speakers are targeted toward crowds, such as information sound beams used for museum or advertising displays.

These headphones provide the wearer an opportunity for focal audition as one scans the surrounding environment. The differences in sound reflection inform a more detailed spatial image. This scanning method is crucial for perceiving the lateral topography of space. The constantly changing direction of the detection sound beam, the contrast in sound is what informs the spatial surrounding. The mp3 player connected to the Echolocation Headphones has is loaded with a track of continuous clicks and another of white noise. I have found that noise is the most effective sound for this echolocating purpose. When demonstrating his method to an audience, Daniel Kish created a “shh” sound to show the distance of a lunch tray from his face. Noise works well because it provides a long rage of tonality at random, this eases the detection of level and speed change.

Fig. 3.31 Echolocation City Walking

Beyond the applicability of navigation, this tool is also useful for differentiating material properties such as texture. Sonic perception can also inform the somatosensory cortex about physical object based on the surface's acoustic deflection. In one of his studies Göran Lundborg tested the feasibility of artificial somatoception through a system of contact microphones applied to the fingers utilizing sound for tactile substitution.[30] I conducted a series of experiments with different subject to determine that the use of the Echolocation Headphones facilitates the distinction of materials based on sound as the only informative stimuli. Subjects were able to identify distance and resonance within the first 2 minutes of wearing the device. I found that it is very easy for the wearer to identify metals and plastics in comparison to cloth and cardboard because of their different material porosities. The more irregular the surface the less likely it is for sound to reflect from the surface. This is why foam and cork are used to line the walls of recording studios.

When experiencing the echolocation headphones, one of my test users Joi Ito, noted a very beautiful analogy from noise to space. He said that in blindness one can finally see it all when it rains. The noise that occurs with the dripping of rain creates a detailed map of the environment. This notion of utilizing sound to navigate space is not particularly useful for sighted subjects, but this device depicts the experience of sensory substitution and it exemplifies the agility and plasticity of the brain's perceptual pathways.

3.4 Scent Rhythm

Fig. 3.32 Scent Rhythm Watch Face

Scent Rhythm is timekeeping device that maps relational olfactory sequences to the body's circadian cycle. The sense of smell is a chemoreceptor, which means that these sensors can detect chemicals. The sense of time, chronoception, is not based on the function of a specific organ, but rather the result of the interaction of the cerebral cortex, cerebellum and basal ganglia. This device attempts to keep a chemical watch on the circadian rhythm, by administering fragrance+supplement concoctions associated with the daily activity of the moment to promote the production of certain neurotransmitters, such as chamomile+melatonin during sleep, espresso+caffeine during awakeness.

3.4.1 Precedent

The suprachiasmatic nucleus is responsible for controlling the circadian rhythms. Jonathan Fahey refers to this area of the brain as a personal assistant embedded in the middle of everyone's brain.[20] Researcher Daniel Forger, a mathematics professor at the University of Michigan, uses math to study biological processes. He has found that the SCN has two types of cells, ones that have a strong molecular clock and others that are similar to common brain cells. These cells that have a strong molecular clock are very active during the rest periods of the circadian cycle. Alterations to these cells such as a tau genetic mutation can change the circadian rhythm cycle time from 24 hrs to 20 hrs for example.[20] Another form of altering the circadian rhythm is the use of chemical supplements that influence the flow of the sleep-wake patterns, may it be by delaying it or by inducing sleep.

Fig 3.33 Carolus Linnaeus' Horologium Florae [3]

The mapping of scent to is not that far fetched of an idea. Carolus Linnaeus known as the modern father of taxonomy was a Swedish botanist, physician, and zoologist. He hypothesized the Flower Clock which was a garden plan that would measure time based on the flowers' opening and closing at particular times of the the day. He called it Horologium Florae ("flower clock"), and proposed the concept in the 1751 publication of Philosophia Botanica.[29] This natural fragrant clock could determine the time with the accuracy of one to two hour intervals based on flowers in Linneaus's hometown, such as Chicory which opens from 4-5:00 am and the Scarlet Pimpernel that opens at 8:00am.

Other examples of this mapping function are explored by Joseph Nathaniel Kaye in his thesis Symbolic Olfactory Display. He collaborated with Daniel Bedard for one of his case studies called the Scent Reminder, a five-channel smell output device. This device is similar to Scent Rhythm except that it is a large device designed to function like a clock, rather than a wearable watch. Through his design thinking he notes that computerized schedules are very quantized and the accuracy of alarms cannot give a gradual notification. Instead he believes in the potential of smell cues to serve as gradual alarms by increasing in aromatic intensity as the reminder approaches.[27] Hyun Choi, a Korean designer, created "Smell Time" a clock also grapples with the same concept of mapping symbolic scents to the passing of time. This clock functions very similarly to Kaye's case study, except the chosen smells are more arbitrary.[28] For example, Choi's clock smells like apple at 2 o'clock and cherry at 4; this method is contrasted by both Kaye's study and Scent Rhythm. Smell Reminder smells like baby powder at 3:00pm to remind a father to pick up his kids at 3:30pm.[27] Scent Rhythm utilizes associative smells to mark parts of the day in 6 hour sections, from 6-12pm it can smell like espresso or waffles, even earl grey tea. This device is also paired with chemical supplements that induce the action state of the day, for example by adding actual caffeine to the scent of coffee. Body architect Lucy McRae in collaboration with synthetic biologist Sheref Mansy developed Swallowable Parfum fragrance-releasing capsules.[53] Like, Scent Rhythm, this project also makes an explicit connection between chemical supplements and scent. The fragrance molecules of this perfume are excreted through perspiration, and this process facilitates hormone mixing which result in a unique odor for every user.

Fig. 3.34 Swallowable Parfum [25]

The sense of smell is classified under chemoreception, it lies on what is called the glomerulus. This structure that transmits signals to the olfactory bulb, which is located directly above the nasal cavity and below the frontal lobe. Mammals have two distinct olfactory systems, the main olfactory system, used to detect common scents, and the accessory olfactory system, which contributes to the selection of mates by sensing pheromones.[47] Artists Auger and Loizeau invented a contraption called Smell+ that allows 2 people to perceive each other's pheromones through scent before deciding their level of attraction based on sight, touch, or hearing. This augmentation facilitates a new interface for mate location, and expresses the social aspects of olfaction.

Relationships have an important chemical effect in humans as social beings. Routines and schedules inform societal daily rhythms as strongly as photic perception, which is the grasp of light through the liquid layer of the skin. Circadian rhythms, which are the approximate 24 hr cycles of living organisms, are reset once a day and can be altered by environmental time cues also known as Zeitgebers, "time givers", this process of resetting circadian rhythms is called entertainment. Jürgen Aschoff found that light is a weak zeitgeber for human beings, and that social cues and mealtimes are sufficient for entertainment.[18]

3.3.2 Experimentation & Functionality

Fig 3.35 Scent Rhythm: User Interaction

This test begins by analyzing chronobiology, what gives us a sense of time, and how is time perceived in the mind and the tools that we have created to coordinate events. In order to answer these questions I have researched the socio-chemical effects on the processes of the circadian rhythm. It explores the design process of a model for olfactory chronoception by examining the most suitable platform for this idea and testing the conceptual form of associative relational scent and time. This section details the quest of making a functional and conceptually sound prototype. This system induces the changes of the circadian rhythm based on comparative smell memory formation and chemical receptors.

Thinking about time in as a process of chemical events in the brain, has led me to investigating the potential of olfactory perception and time. Olfaction being the most complex of our chemoreceptors can perhaps influence our circadian rhythm. Most of our time perception tools are based on visual perception such as watches, clocks and digital displays. Accessible manifestations of these include vibrotactile watches, braille watches, and talking watches. This is not including calendars or other more complex measures of timekeeping tools, such as accumulation or storage of digital data, just the perception of the 24hr-+ circadian cycle.

The embodiment of this device is a watch that facilitates chronoception through olfactory maps, keeping track of the chemicals needed in the body's circadian cycle. I want to find smells that can induce the production of particular neurotransmitters, the chemicals consequent for synaptic activity in the brain, to induce sleep-wake cycles. What smells induce the production melatonin, dopamine, serotonin, and acetylcholine? Do these neurotransmitters have a scent? Does our psychological perception of scent- e.g. incense= relax, coffee= wake up, directly related to the chemical synapses they induce?

There are deeper chemical connections to our associations of smells with certain "moods". What if a watch releases melatonin supplements at night? Melatonin is the chemoreceptor released by the pineal gland, and it controls sleep cycles. What if this watch could administer almost homeopathic doses to induce the natural production of melatonin in the body? Keeping in mind that supplements like these are available over the counter, and that the dosage will be less than any harmful exposure to the skin. It is known that the moods induced by certain smells are linked directly to memory, therefore; the chemical composition of most fragrances has less to do with the psychological state. Because of this I have opted for adding chemical supplements directly to the scented vials such as melatonin, caffeine, gingko biloba, and valerian in miniscule amounts, almost homeopathic in order to support the psychological effects of scent memory triggers. This device has 4 ultrasonic atomizers which go off in a 24hr cycle, it activates scents+supplement concoctions that induce the triggered neurotransmitters 4 times a day. Will this be helpful for people with insomnia, or other type of sleep disorder?

Dissecting our time tools:

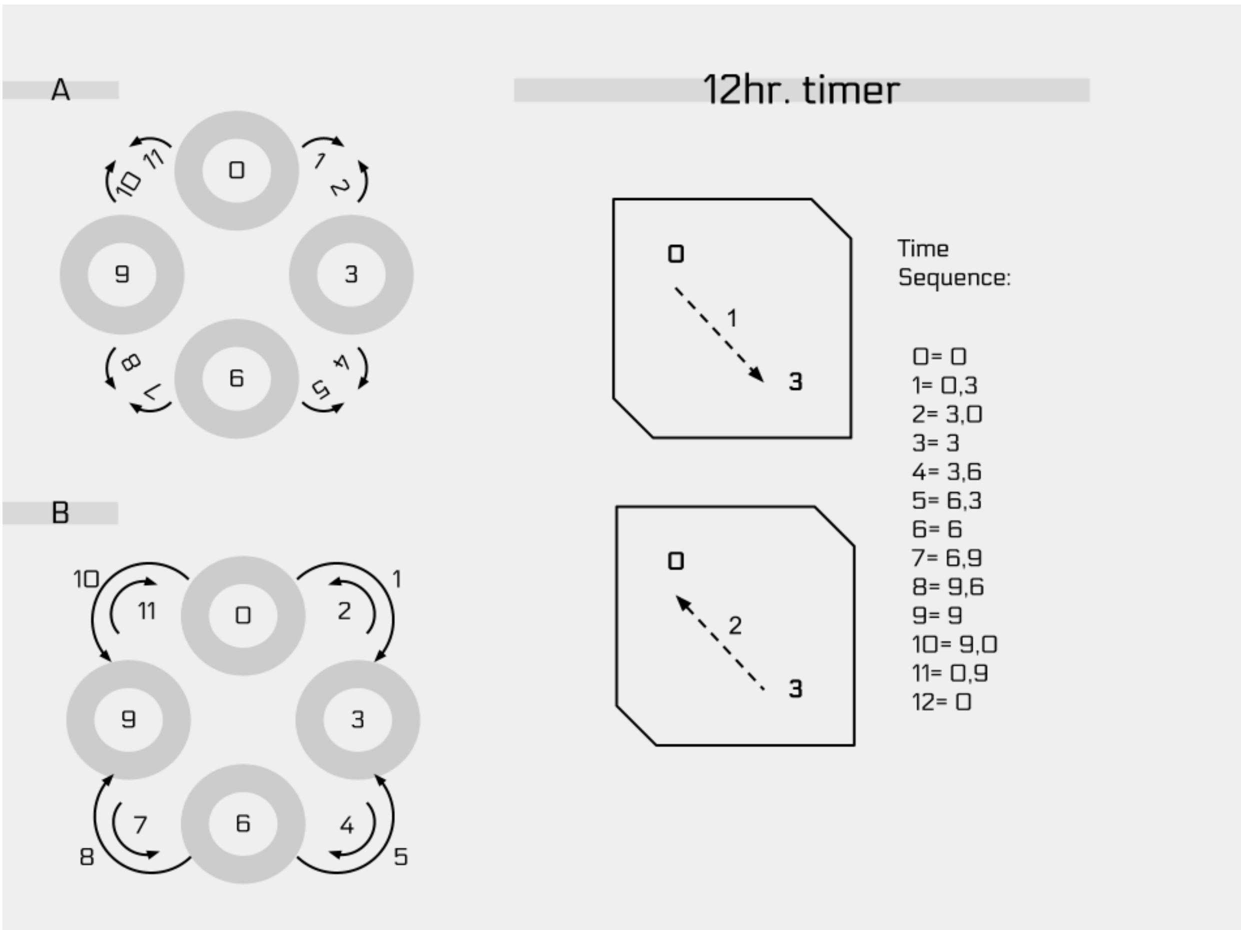

Fig. 3.36 Scent Rhythm: 12hr Timer Diagram

This is the first model of exploration for the chemical watch. During the formulation of this design, I was questioning the idea of olfactory based math and the spatial-temporal perception of scents. Thinking about how to determine a more precise measure of time with smell is a challenge, because chemical particles are harder to dissipate. The diagrams A and B in Fig. 3.36 are two diagrams of the same concept. The time sequence breaks down the temporal coordinates for each scent in order to arrive at a specific hour in a 12 digit cycle. If 0 is detonated solely, then it means it's 12, with no distinction between PM or AM like a dial clock. If the detonation occurs first on hour 0 and then later hour 3, then the time is hour one because it is 0 almost to 3. In order to arrive at the second hour the detonation would occur as a subtraction, such as first 3 but still close to 0. This model is complicated, and it requires a lot of attention. A clock that outputs scent cannot be as precise as the visual tools that exist. Adding a smell for each hour could be a bit disastrous as each clock would become a concoction of scents, which is not necessarily a bad thing but rather another opportunity. Making sense of the chemical reactions and chronobiology has steered my thinking to a 24 hour cycle four part cycle. This means that we can forget about splitting the day in 2 sequences of 12 and utilize the natural 24 hour rhythm.

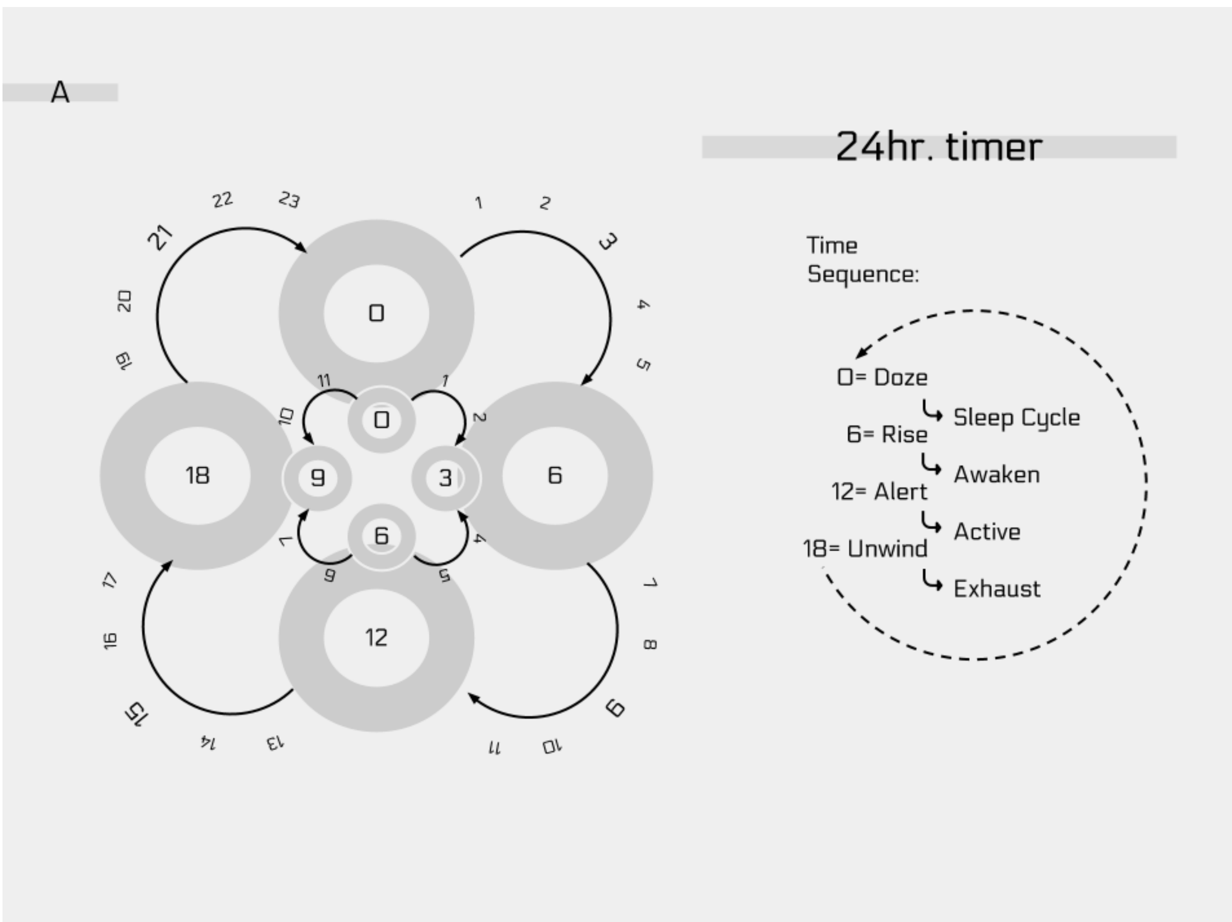

Fig. 3.37 Scent Rhythm: 24hr Timer Diagram

In this model has forced me to rethink the day in a much more basic analysis. Diagram A is showing the hours organized in a 24hr cycle in the outermost, lets call it “flower”. The inner flower is a 12hr cycle as a point of reference for those who are not used to military time. It certainly helped me. On the table beside it the 4 diffusers are numbered 0, 6, 12, and 18 hours. These hours mark important points in the wake-sleep cycle, such as dozing at 0 hrs., rising at 6 am, being alert by 12pm and unwinding at 6pm. Consequently these stages give a large gradient encompassing most people’s daily routines. This watch can also be set to personal preferences, such as sleep cycle beginning at the 12hr atomizer for a person who has a shift-work schedule for example.There is no gradient of smells between the phase detonations, such as the state between Doze and Rise or should their be a detonation at all. Is this not a time keeping tool, but rather a chemical watching tool?

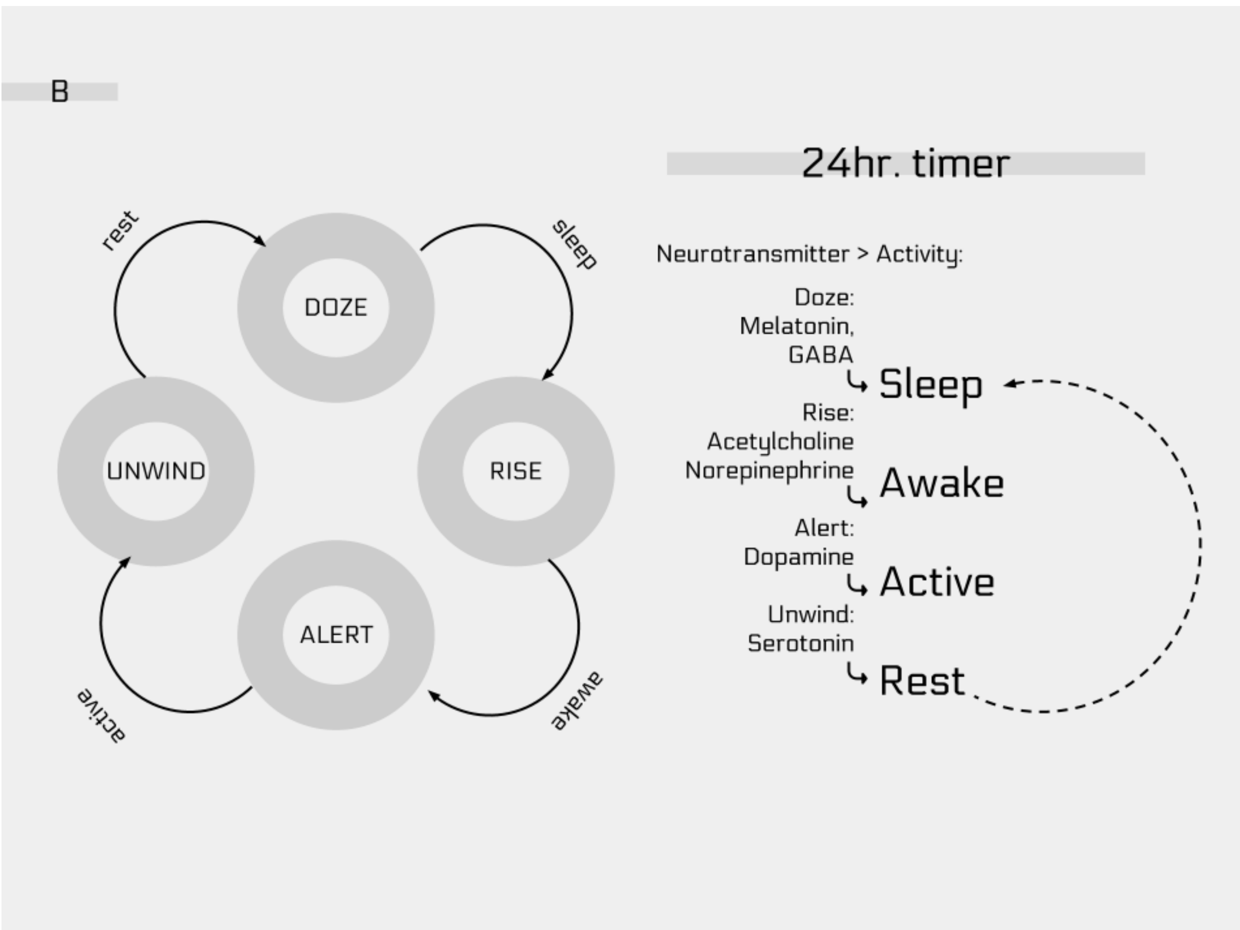

Fig. 3.38 Scent Rhythm: 24hr. Activity> Chemical Mapping

The 24 hr model is the most successful by providing 6 hour interim cycles and breaking the day in four important events. Fig. 3.38 shows an expanded view of the sequence and the its stages, stripping the model from numbers, and looking at the qualitative properties of the cycle. On the table beside diagram B you can see the neurotransmitter that is being triggered at that particular stage. It is still unclear of what measures to use while administering these chemical substances. Are there over the counter supplements that can provide all of these neurotransmitters? Are there other chemicals that can induce the natural production of these neurotransmitters in the brain? I have heard, not yet researched in depth, that mint has an focusing and learning improvement effects. Does this mean that it promotes the production of dopamine? What neurotransmitters are affected with caffeine?

What are the implications of watch administering drugs? (not illegal ones because that is an obvious answer.) Can this change how drugs be delivered to patients? Can this have a larger impact for the medical industry? One of the problems that patients face when given a prescription is remembering to take a medication. Could timer atomizers become an approve medicine delivery method? From a user interface design perspective- What are the problems associated by air-borne medicine administration? Is there social implications- What is the short term effect of this chemical dissemination?

Fig. 3.39 Fragrance Bottles and Chemical Supplements

Fig 3.40 Scent Rhythm: Fragrance Globules

The fragrances chosen to fill the watches globules are: Espresso with caffeine supplements for the Rise period which runs from 6:00am- 12:00pm. Paper and Tarnish were chosen for the afternoon Active period that lasts until 6:00pm to elicit the smell of money. I wanted to trigger brain functions associated with productivity, so this globule is also supplemented with Gingko Biloba. The Rest period runs from 6:00 pm to 12:00 am, and it smells like whiskey and tobacco. In this period the user should be induced in a state of relaxation, so this scent is combined with a Valerian extract supplement. The last stage is the Doze period that begins at 0 hrs and continues to 6:00 am. This period smells like chamomile and it elicits sleep with a melatonin supplement.

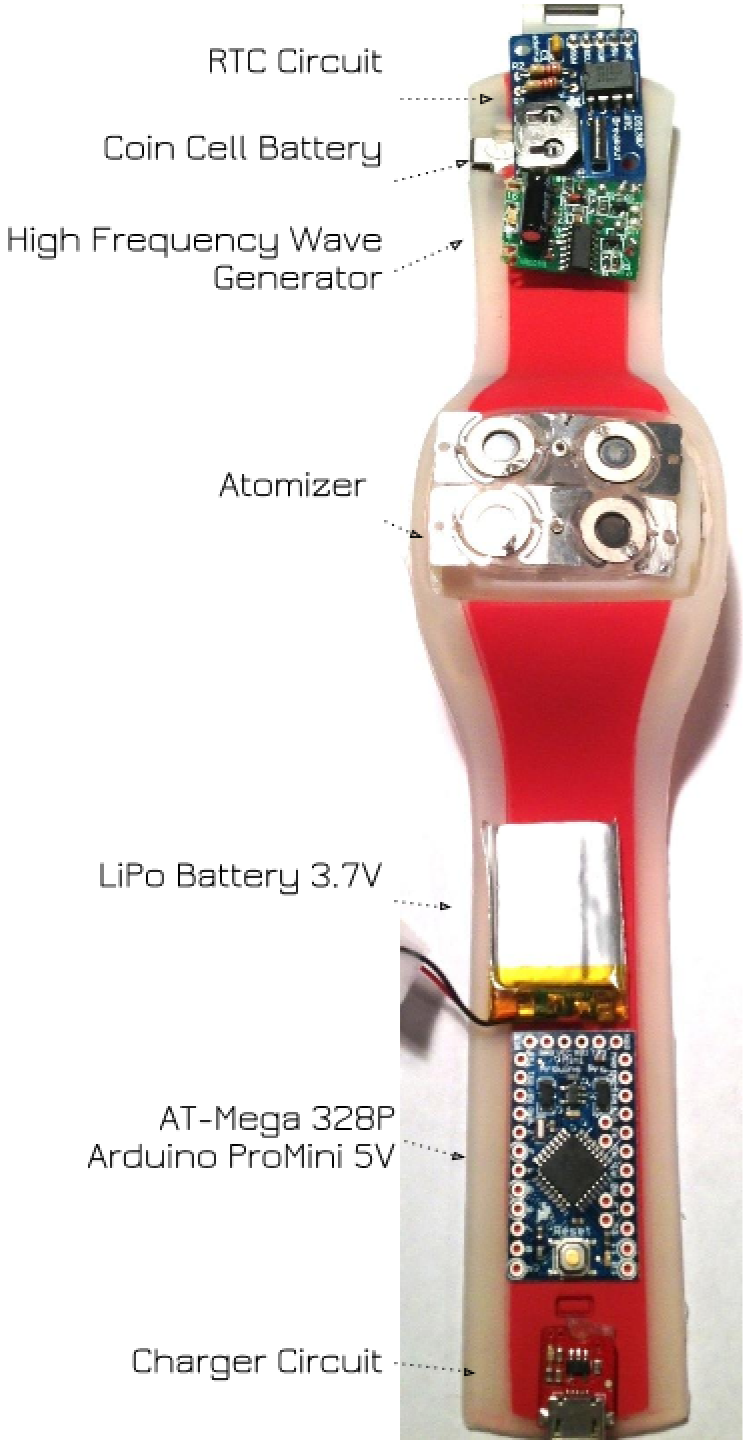

Fig. 3.41 Scent Rhythm: Components Diagram

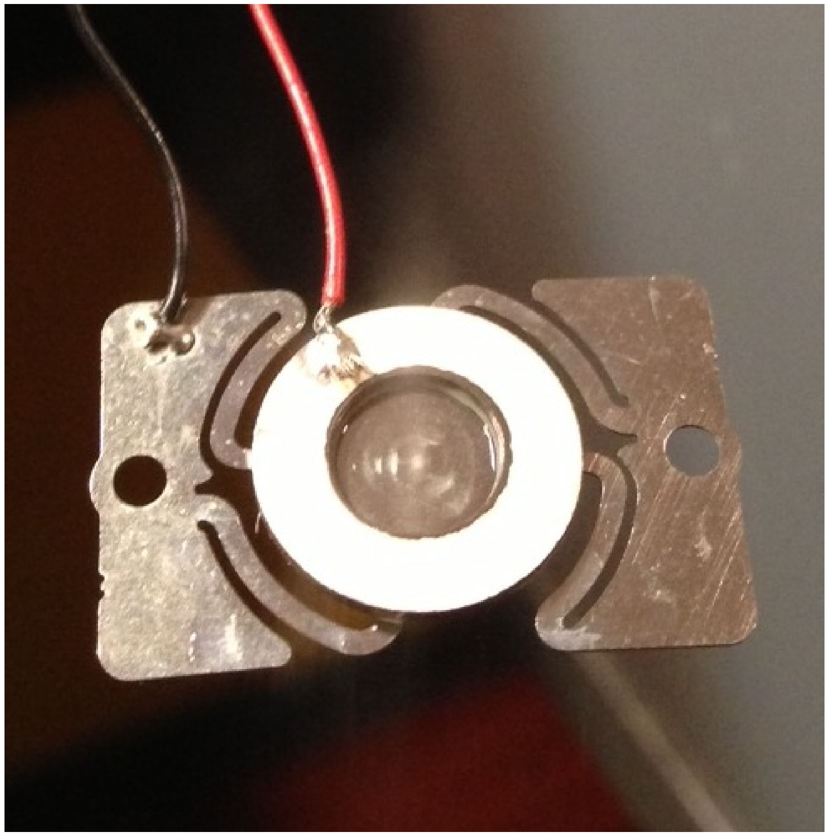

Fig. 3.42 Atomizer Function

Scent Rhythm was developed by combining a modular series of circuits that could form a larger circuit that wraps around the wrist. The design of this watch was based on a USB atomizing device that contained one atomizer, a high frequency generator circuit and a USB connector for power supply of 5V. The atomizer uses piezo vibration at a high frequency to achieve the atomization of liquids that result in a mist. The piezo plate is different than a typical buzzer because the bottom plate is a thin grate that allows the liquid to flow upwards, as the piezo crystal flexes with the pulses of the driving circuit, the molecules disperse. Scent Rhythm utilizes 4 atomizers that were extracted from four of these USB scent atomizers. I was able to reuse the high frequency generator circuit for these four atomizers by utilizing relays and a the pro-mini Arduino microcontroller. This method allows me to select programmatically each atomizer individually. The Real Time Clock circuit informs the time actual time to the microcontroller. Once it the time is set on to the RTC, the watch can be shut off and still keep track of the time. It does this by powering this circuit independently with a coin cell battery, which will remain operational for 6-7 years. The design of the RTC circuit was based on the RTC break-out board created by Adafruit.[17] Their RTC timer library was also implemented in the code. I redesigned the layout of their circuit and printed it on the pcb milling machine at parsons. The relay and atomizer circuit was also designed in Eagle Cad and milled with the same process.

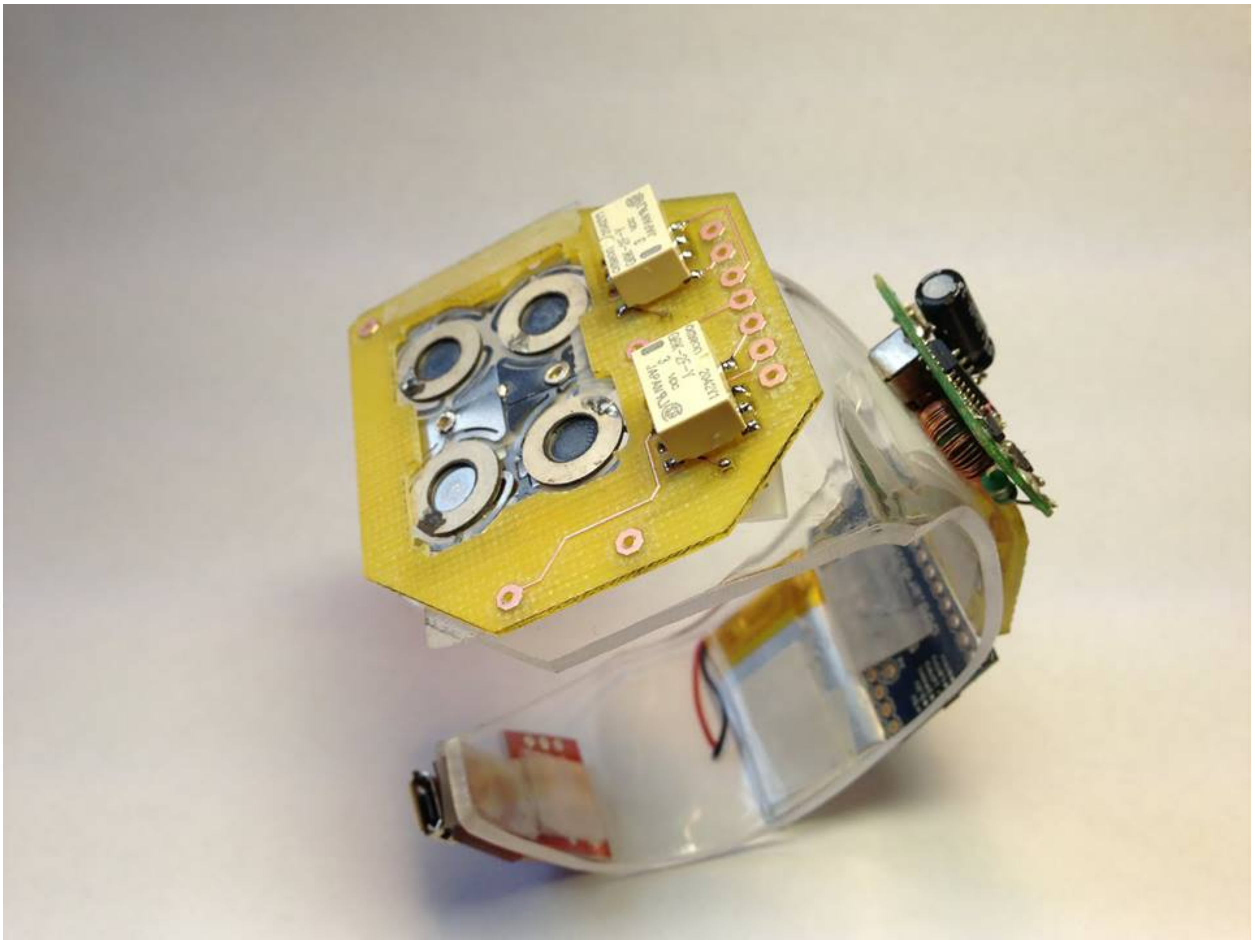

Fig. 3.43 Scent Rhythm: Electronic Layout

The rest of the components of the components that make up the Scent Rhythm watch are the LiPo battery a 5V power stepper and a mini-USB charging circuit. This device can be charged with any 5V wall adaptor that has a mini-USB connector, similar to the ones used to charge cellphones today. The power stepper obtained from SparkFun electronics is a circuit that amplifies lower voltages to a constant 5 volts. Even though the wall adaptor is already supplying 5 volts to the circuit, we need a power stepper because the lithium battery holds a charge of 3.7V, but the microcontroller and the high frequency generator need 5V in order to operate.

Fig. 3.44 Scent Rhythm Button Functionality

Beyond pulsing smells based on the RTC inherent function of the watch, I added a feature similar to an alarm. The user can push the only interfacing button to trigger certain smells whenever they need to make a memory reminder association. If the user presses the button once, the atomizer on the top left corner is triggered, if the button is pressed twice consecutively the top right atomizer is triggered, and so on for the next two atomizer in a clockwise order. Once the user has gotten a whiff of the fragrant reminder, in order to reestablish the original time scent, the button must be pressed for 3 seconds. This is a play on the idea that scent has a strong connection to memory retrieval.

3.3.3 Evaluation of Potential

During this test I have found that there is an interesting potential in linking the sense of smell and time, because both of these are chemical processes. The challenges in designing psychological states concoctions maps from the sense of smell to time arose from understanding the temporality of scent itself as a transient slow process. The messiness of having fragrances detonating at very short intervals of time has proven to be ineffective when working with the media. This has been shown in the case of smell-a-vision, where films were decorated with scent as the movie progressed in theaters. Most theaters were a stinky soup by the end of the show, and so this multi-sentient experience was discontinued. When hypothesizing about mapping every hour, I was collecting a general diagram of the smells surrounding particular times of the day. Mapping blocks of time makes more sense for complying with the body's natural cycle, for example, 6:00 am = fresh cut grass vs. 6:00 am -12:00pm = espresso. When mapping single hours to arbitrary *possible* instances of scents, it felt that there was no actual substance to the idea- you can map anything to anything, but what's the point?

Once I researched thoroughly on the sense of time, I stumbled upon the fact that the circadian rhythm is mainly driven by chemicals released based on the effects of the environment, and also the necessity of entertainment in a cycle of about 24 hrs. I have found that the scents that are thought to be relaxing, or other, are based on memory, and in order to have the production of neurotransmitters that pertain to that feeling, a chemical supplement is necessary. Can the smell of coffee, without ingestion, simulate the effect of caffeine for a small amount of time- and perhaps jumpstart an awakening state in the body? This could be an interesting test: Smell coffee in the morning, without ingestion, is there an awakening effect? Perhaps there are some studies done with the effects of caffeine free coffee. How many people have a placebo effect? Are these placebos jumpstarting natural processes in the body through psychology?

This case study has left me with more inquiries to be investigated, such as the effects of low dosage chemical supplements to be disseminated through scent and their potential placebo effect that created a chemical jumpstart. I am also interested in the potential medical applications for this kind of device, even if the vials are filled with over the counter medications prescribed by doctors. There is actual practical potential in this idea for the upgrading of spray drug interfaces.

Overall, this watch relates to the my thesis because it explores the cross-modal mapping of chronoception to olfaction. This view of time is novel, and it can provide a new understanding of time through a chemical perspective. Though this idea is not directly related to assistive technology- it could have positive outcomes if used by people who have circadian disorders. Interestingly a lot of blind people suffer from conditions like these because of their lack of light perception which can kickstart the cycles of entertainment.[44] Unlike most of the other case studies- this comes from pure inquiry and not from extending the use of some assistive technology. This idea encompasses both people in need and people curious to explore their sense of time through their nose.

Chapter 4:

Conclusion

This thesis contributes to the sensory substitution and brain plasticity fields and its intersection with art and interface design through the development of experimental devices. The case studies are largely inspired by previous work in the symbiosis of these fields as an attempt to bring new possibilities of new data sensory displays to the public at large. The significance of this research is finding applicable and functional proof models through iterative prototyping and testing processes of design thinking and construction. One of the methods of this research has been to unpack existing “synesthetic” hardware devices, such as assistive technology, and to redefine its user base by generating new approachable designs. The intent is to generate interest for these experimental models that facilitate the use of new modalities to inquire in their potential application. These case studies evaluate the interfaces for testing cross-modality and it’s usability for computing devices.

Sensory substitution is a learning process, the plasticity of the brain is subject to various factors such as age and brain development. Some brains take longer than others to process sensory mapping functions, for example, a child’s developing brain will be able to create connections faster than an older subject. This does not mean that older subjects cannot experience sensory substitution, but rather will take longer to experience the effects. This is mainly true in the tactile to sight experiences, such as the PopMatrix. This device has a much higher learning curve than any of the other case studies in this research, because of the complexity of mapping and the low resolution achieved in my iteration of the device. Other cases such as the Play-A-Grill require almost no learning curve whatsoever, the function of this device is rather repurposing the hearing channels and surpassing the eardrum. In this case, the only subjects that may have trouble experiencing bone conduction hearing are those with false teeth, or those with damaged hearing at a neuronal level.

These devices provide an alternate route to perceiving our surroundings. Some of these devices are inspired from accessible technology because it aims to answer some of the same questions I am asking: How else can we perceive data or information about our environment? Accessible technology devices, such as the brainport and bone conduction hearing aids, have much more potential than their assistive capabilities. Computing is becoming more integrated with our physiology, and as it becomes ubiquitous, new interfaces will have to be developed. This is a study about the technologies that can be used as alternative outputs- if we don't have screens or speakers, how else can we perceive this information? You could listen to music through your teeth, you could listen to space, you could taste drawings, you could smell time. It sounds like synesthetic hardware, but this could be how you connect to your environment one day in the future.

The potential in designing for alternative perceptual models of information display is to serve the ubiquity of digital hardware. Embedding sensory and communication technology devices is the present goal spearheading the mobile computing revolution. Wearable information displays are becoming ever more prominent, as electronics miniaturize with more processing power and less energy requirements. As a visually driven species, most of these devices revolve around screen based displays. Rebelling from this visual sensor model, these case studies contribute to the scarce research in alternative sensory display applications, since they were termed as assistive technology until now.

4.1 Design Inquiry Summary

This section summarizes the design thinking process driving this research. It breaks down the key concepts that have spun the deployment of the case studies, and shows the curiosity driven mindset throughout the process.

How are these methods deployed?

-Designing through focused basic research

inquiry>> creativity>> making

-Understanding brain plasticity / limits

-Understanding the senses

-sight - audition - olfaction - somatic - taste - nociception- chronoception - proprioception- thermoception.

- physiology: body wiring- interfacing and finding anomalies in our fleshy circuit.

-inputs and processing

-perceptual crossover

What is the focus of this research?

To deploy experimental devices designed in popular context to instigate alternate modes of data display utilizing concepts of sensory substitution and perceptual anomalies of the body's circuitry.

What are the outcomes of this focused basic research?

-Discovery of sensory anomalies

-New ways of accessing our sensory inputs eg. Listening through teeth

-New senses, plug and play, eg. Magnets in fingers allows us to feel electromagnetic fields.

-Synesthesia

-Savant Syndrome

How does this lead to applied research?

-Defining substitution experiment cases to be iterated and improved.

-Molding the application and theory

-Expanding the platform of existing research for device development

-Hardware development and improvement

-Providing alternate displays from a utilitarian perspective

-Moving away from the screen

-Developing devices with a creative approach to information perception

-Instigation of the development of the future human. What features do we add?

4.2 Evaluation

There is potential in creating more interfaces to further this research. The importance of these devices lies of the experience and the effectiveness of the tool to produce cross-modality.The quest for finding new perceptive pathways goes beyond the usefulness of the tools, more creative applications for information display can surge from of the theories that I have experimented with in this research study. My main interest is to understand perception, incite new possibilities for interfacing the body with electricity, and to provoke new ways of interpreting information.

This research has cross-cultural identities as well as cross-modal perception. It appeals to members of the Art-Sci community, technological display innovator, data representation artists, and the general public alike. People are interested in experiencing novelty, and respond to cultural references in the presentation physiological phenomena. The success of the Play-A-Grill is the best example of the interested generated throughout this diverse audience. Bone conduction hearing is not an entirely new concept, but not many people know that they have experienced it every time they eat something crunchy. Relating this technology to popular Hip Hop accessories creates a catalyst between the scientific and artistic modes of thinking. It gained international traction, selected by the press as Project of the Month by Popular Science, featured in the Future Tech segment of Discovery Channel, and mentioned worldwide as a novel invention. Without a doubt the contrast of Hip Hop and science colliding becomes a spectacle of social occurrence.

The tongue display units present an attractive representation of electronic candy. The sensory function of this device takes time and practice to be perceived; therefore, the physiological phenomena is not as immediate as bone conduction. Experimental devices that shift current modes of visual display represent a slow progress in our oculo-visual driven society. The future brings sensory extended displays such as localized haptic feedback in touch-screens. Our brains have the capability to be fluent in visuo-spatial mapping, but perhaps this point of somatic focus is better suited for the fingers rather than the tongue.

Similar to the PopMatrix technology, the Echolocation Headphones provide the wearer an opportunity for focal audition for visuo-spatial mapping. The differences in sound reflection inform a more detailed spatial image, similarly to the difference in perceiving the texture and topography of space. I have gained a new understanding about perception from the testing results from both of these devices. Perception is realized by the contrast of signals, constant change must occur in order for signals to be detected at all. I have also learned that the process of creating these devices by stripping objects from their original functionality and reconfiguring their sensory stimulation also functions with a similar cognitive process of visuospatial mapping.

Overall, these devices have the potential to be developed as products, but in order to reach this level they must undergo many more prototyping phases. The goal of inquiring about new interfaces for cross-modal computing has been fulfilled as a research based exploration. The outcome of these case studies is not necessarily to achieve an actual product but rather a playful exploration of experiential design. The wearability of these devices incites requests from the public to push these to the next level of manufacturing. This proves that my attempt to familiarize the general public with physiological phenomena by popularizing and appropriating the cultural identity of common devices has worked. People seemed to be excited to perceive the world in a new way; whether it is understanding of time through a chemical perspective, such as smelling time through Scent Rhythm; or experiencing space through physical perspective by licking or hearing in PopMatrix and the Echolocation Headphones; or listening through their teeth via bone conduction. These devices mimic extraordinary abilities and serve as training apparatuses for further engraving alternate new path of perception to discover what non-obvious evolutionary traits our species might benefit from.

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