EVALUATION OF A HAPTIC TONGUE DEVICE

by

MARK EDWIN BAILEY

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Dr. Sarah Douglas, Chair of the Examining Committee

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Date

Committee in Charge: Dr. Sarah Douglas, Chair
Dr. Kent Stevens
Dr. Scott Frey

Accepted by:

Dean of the Graduate School

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Title: EVALUATION OF A HAPTIC TONGUE DEVICE

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Dr. Sarah Douglas

Haptics is the interaction with a computer through the sense of touch. Previous research has shown that the visual cortex is able to process spatial information obtained through the skin. The highest concentration of touch nerves is located on the tongue. This thesis improves a prototype device that has been built to fit onto the tongue and receive visual information in a tactile form. Possible applications include its use as a prosthetic device for visual impairment and multi-sensory environments. Two contributions are made: First, increasing the resolution of the device and introducing virtual points as representation; and, second, conducting a series of experiments with human participants to evaluate the effectiveness of the device.

CURRICULUM VITAE

NAME OF AUTHOR: Mark Edwin Bailey

PLACE OF BIRTH: San Dimas, California, U.S.A.

DATE OF BIRTH: March 28, 1976

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon

California State University, Northridge

Pasadena City College

DEGREES AWARDED:

Master of Science, Computer and Information Science, June 2007, University of Oregon

Bachelor of Science, Computer Science, June 2005, California State University, Northridge

AREAS OF SPECIAL INTEREST:

Human Computer Interaction

User Interface Design

Computer Accessibility

PROFESSIONAL EXPERIENCE:

Software Programmer, EarthLink Inc., 1997-2005

Research Assistant, Dept. of Psychology, University of Oregon, 2005-2007

GRANTS, AWARDS AND HONORS:

Department of Computer Science: Boeing scholarship, California State University, Northridge, June 2004

Engineering & Computer Science Academic Progress Achievement Award, California State University, Northridge, October 2004

Leon Culbertson Scholarship, University of Oregon Graduate School, January 2007

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CHAPTER I

INTRODUCTION

Approximately 45 percent of the human brain is used in some manner for vision. It varies widely from finding edges and object recognition to judging distance. Evolutionarily speaking, this is a great cost for this high percentage of the most resource-costly organ in the body to be used for one activity, unless, of course, vision is broadly involved in cognition.

With so much of the brain being used for vision, what if a person's vision is damaged? What about the situations with people with normal vision that must attenuate between two visual oriented tasks at the same time? If only there was a way to tap into the brainpower used for vision to route information around malfunctioning sight or to feed different information in for multi-tasking.

One of the larger questions that arises is whether it is possible for the human brain to translate the sensation of touch into spatial comprehension. There has been research done using fMRI that shows that a region in the ventral visual stream, the "LOtv", responds to both visual and tactile objects while other senses such as auditory cues are handled by different areas in the temporal lobe (Amedi, 2002). Since sight and touch are the closest functioning senses within the brain it makes touch a prime candidate if something were to happen to someone's sight. However, usable vision would need to be more then visualizing static images. A portion of the brain used for processing visual motion, Area MT (V5), can also react to processing tactile motion (Beauchamp, 2005). While both of these areas are strongly present for tactile responses in people who are congenitally blind, they have also been shown to be present in normally functioning humans. This proves at least a probable anatomical path that information could travel should the need for spatial and proprioception information be transmitted through touch.

Main Questions

This thesis is about the use of touch as a form of sensory substitution. Specifically, it covers the creation and use of electrical stimulation on the tongue to convey spatial information well enough to assist or replace sight. This is possible through what previous research has found that the visual cortex in the brain is used for more than just vision. It is capable of detecting and processing spatial data from the skin as well.

The next largest question would be, why the tongue? Since sight uses such a high number of receptors, finding the area of highest concentration of tactile nerve endings would allow for higher resolution of "vision". The smallest distance between the nerve endings determines the resolution that is possible. Having participants guess the orientation of grating on a block is a method used to find the smallest distance someone is able to discriminate points. It is more accurate than the technique of distinguishing when two points become one. The most resolved areas of the body are the lips at 0.55mm, the tongue at 0.62mm, and fingertip at 1.00 mm. (Van Boven, 1994). This is the highest average resolution possible since the measurements were obtained from 23-25 year old participants. The reality is for many manual labor professions or as someone ages their sense of touch also lose resolution. Just as with video screens, more contact points could be devoted to convey each "pixel" at the sacrifice of higher resolution for those who have lower tactile ability.

Motivation

While there is hope using artificial retinas or tapping sensors directly into the optic nerves the operations needed to even study these approaches involve very invasive surgeries. There are also the ethical problems of leaving permanent consequences for experimental research. For many of the studies now being done in these areas, once a participant has had an operation there is no longer a chance of getting a different implant. As the affected nerves die, or if improvements are created from the research they were involved in, they would not be able to benefit from the better technology.

Bypassing malfunctioning eyes without an operation is researched in the field of sensory substitution. The next highest concentration of nerves used for perception outside the eyes is through the skin. Skin contains the ability to process spatial information transmitted to it through a haptic display. The goal of using the haptic display on the tongue is to allow for a temporary means of sensory substitution by using touch and proprioception instead of sight.

The most obvious use of the haptic display is for use with people with limited or no sight. The other lesser-known area would be for use as embedded devices for sighted people. The haptic display could be used in situations where more then one task must be attended to at a time. Anytime multi-tasking is required the haptic display in addition to vision and sound could help.

Contributions

Dr. Bach-y-Rita and others have studied the sense of touch as a substitute for vision extensively (White, 1970; Bach-y-Rita, 1998; Beauchamp, 2005). A constant theme in the research has been the problem of resolution. Vibration based actuators have never been built small enough and electrical contacts have had problems of shorting between the contacts when too close together.

This thesis builds on previous research in sensory substitution by using two different approaches to improve resolution to a haptic display. First by only activating one contact at a time we are able to put the contacts closer together without the worry of electrical shorting between contacts. This is possible because as long as the contact points are able to cycle through a frame in under $1/40^{th}$ of a second, then the brain will see it as all contact points being activated simultaneously.

Secondly, by activating electrical contacts in rapid succession, the brain is convinced that only one contact was activated with a location somewhere between the two actual contacts depending on the how many times and the duration of the strobing of the electrical contacts.

A hardware prototype was designed and built to test these two central ideas. Algorithms were created to activate virtual pixels correctly. Software was written to interface between the haptic device and a camera. Finally, an experiment was designed and administered to test these approaches on participants to find if they are successful. Data was collected from all tests and is presented here in this thesis.

Approach

Chapter 2 explains the background of haptics and how the brain is able to receive spatial information through the skin. Chapter 3 covers the building of the prototype and compares it to previous research. Chapter 4 reviews the experiment and results. Chapter 5 covers the conclusions and discusses future research.

CHAPTER II

BACKGROUND

Explanation of Terms

The word haptics, when used in the sense of computer use, has taken on the meaning of sending and receiving information to the computer user through the skin and body. Cutaneous interaction is done through the skin and kinesthetic interaction is through joints and muscles (Loomis & Lederman, 1986). Tactile interaction has to do with perceiving surface textures such as slip, roughness, hardness, and rigidity. Kinesthetic interaction has to do with perceiving movement such as position, vibration, viscosity, and inertia.

Most haptic interaction is currently done using point-force devices, such as SensAble's Phantom (SensAble, 2007) and Novint's Falcon (Novint, 2007). They allow the user to provide input and receive output through a pen connected to motors that move depending on material in the virtual space. They mainly interact through kinesthetic motion, but also allow for limited tactile interaction through varying vibration as the pen moves.

There are also other areas of haptics that are currently not being researched heavily. Pain, temperature, and chemical interaction are not currently large areas of research because of the risks and limited wide spread adoption possibilities.

Proprioceptive interaction has been used for transmitting textures to the skin through a grid of mechanical pins. Sensory substitution also fits into this category since most haptics in this area are based on the spatial relation of activating different areas of the skin.

Sensory substitution is the transformation of one type of stimuli into another. It is most likely used for people missing a sensory modality. However, it is also useful for people with a situational handicap, or high-stress situations, to re-enforce stimuli by presenting it to multiple sensory modalities.

To be effective, the skin must be capable of receiving a high density of information repeatedly at a constant rate. There are different cells for receiving different kinds of information. Merkel receptors handle information 0.3-3 Hz and are the only cells possible to "feel" physical deformation. Meissner cells handle 3-40 Hz and can transduce vibrations. Ruffini cells respond to 15-400 Hz but are more for sensing stretch in the skin so would only help for deep deformation. Pacinian cells can handle 10-500 Hz but only respond for short bursts before becoming over-stimulated (Goldstein, 2006).

Previous Work

Frank A. Geldard first proposed trying sensory substitution by mapping vision to touch in 1957 (White, 1970). Exploration into building devices was started in the 1960's by Paul Bach-y-Rita with the creation of the Tactile Vision Sensory Substitution (TVSS), which stimulated participant's back skin (Weiss, 2001). Most of the research centered on recognizing line orientation and or shapes.

When it started, research was restricted by the size of electronics for the time period. The array achieved at that time was a matrix of 12 by 12 sensors. Even with the lower spatial resolution there was a large enough area for the sensors to be individually felt. Another reason it was hard to place sensors any closer together was the use of vibro-tactile actuators. Another early sensory substitution device was created by Bach-y-Rita to help with lip reading. One side of a belt would vibrate for low frequencies with the other side vibrating for high frequencies. It was able to improve accuracy by 50 percent (Abrams, 2003).

Up until the 1980's the general consensus among neuroscientists was that there was not a lot of plasticity in the adult brain. Minimal effort was put into studying the brain during retraining of the tactile nerves (Abrams, 2003). Instead of trying to retrain the brain to use tactile information to help build a spatial representation in the brain most experimentation centered in helping to recognize predefined symbols. Recognition speeds were compared to reading Braille (White, 1970). Arrays used for the back grew to 20 by 20 vibration actuators. For recognizing symbols the accuracy was similar between sighted and non-sighted participants, but the recognition time of the blind participants was faster at 1.1 seconds as compared to 1.2 seconds for the others (White, 1970).

In the early 1990's, Bach-y-Rita switched to using the tongue as the input receptor. He was able to shrink the original 144 actuators down by switching to electrical impulses. Besides the high density of nerve endings the tongue was chosen because there was a thinner layer of protective skin then the fingertip and saliva allowed for lower voltage use (Bach-y-Rita, 1998). Other purposes besides symbol recognition were starting to be studied as well. It was found that by using the tongue sensor with a mercury switch used for balance someone could "see" his or her own sense of balance. This allowed patients with damage to the vestibular system to be able to walk and function normally (Blakeslee, 2004). Navigation through a three dimensional space was also finally tried when a participant was able to walk along a path in the park.

This realization that the adult brain has plasticity, led to other sensory substitution experiments. Using sound to compensate for vision was created by Mejier who called it the The vOICe. The images were translated into a soundscape (Meijer, 1992). Pitch, brightness, loudness, and left and right balance are affected by the image contents.

Current Work

The current existing technology for sensory substitution of vision to haptics is a matrix of 144 points of stimulation that can be placed on the tongue of someone who is blind, or sighted but blind-folded. The current setup of 144 points is not limited by what was shown earlier, the number of receptive cells available. There was not a reason given in the papers submitted why Bach-y-Rita has not improved the pixel resolution over time. However, problems of shorting between contacts have been mentioned when contacts get too close together. This is the first model that was built for the tongue and was created as more of a proof of concept to make sure the tongue was a viable alternative to using the fingers or back (Weiss, 2001). Even using the reduced number of activators, people that have used it have been able to achieve enough vision to walk in a park (Blakeslee, 2004). As shown in Figure 1, using the sight test of distinguishing the orientation of the character "E", current sight tests using the 144 points result in visual acuity of 20/860 (Weiss, 2001). The cutoff for legal blindness is 20/200.

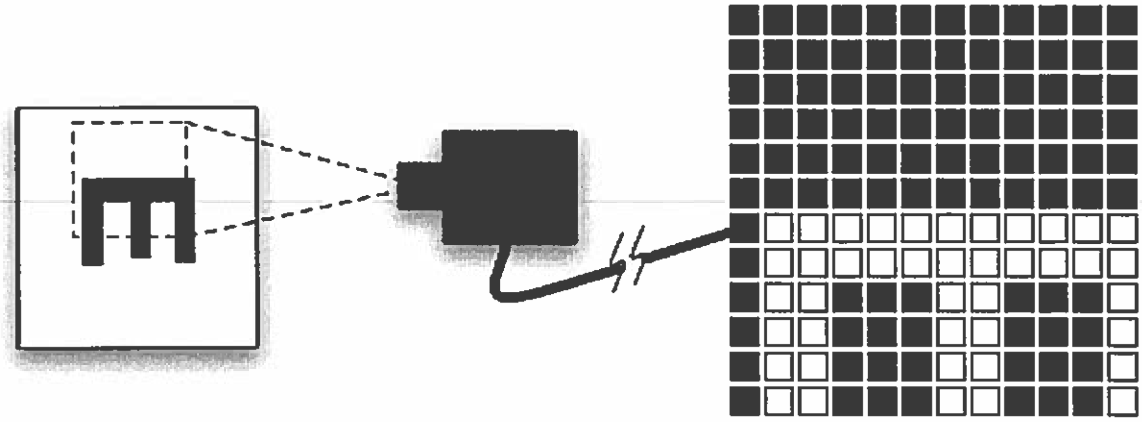

Figure 1: Representation of camera capturing direction of "E" and the translation of pixels, in white, that would be activated on the haptic device.

What the brain is being asked to “see” determines the training time necessary. Normal sight of objects can switch from the “sensation of pop rocks” on the tongue to “x-ray vision” in about two minutes (Blakeslee, 2004). For harder things that are not consciously perceived, such as balance, it can take multiple 20-minute sessions over the course of a few days (Blakeslee, 2004). For those that have lacked sight from birth fMRI studies show that it takes on average seven, one hour sets of trials of no activity showing up in the “vision” areas of the brain before those areas are activated by using tactile stimulation (Ptito, 2005).

As with any good interface that is created to help people with disabilities, it inevitably helps everyone in the end. There is a lot of current exploration happening to use tactile stimulation to enhance and extend the vision of normally functioning adults. Since DARPA funds a lot of the research in this area many of the projects, they are funding are for possible benefits to the military. Helicopter pilots have looked into using tongue stimulation to gain rearward vision (Blakeslee, 2004). Since the helicopter is highly maneuverable 360-degree vision helps tremendously in a combat situation. For airplane pilots the idea of transmitting the horizon line to the pilot is believed to help during combat situations in clouds or near the ground where this information can be lost (Blakeslee, 2004). Underwater, the idea of giving divers the use of sonar would allow for the ability to find objects in complete darkness or silty water (Nelson, 2006). For normal infantry on foot, ideas have both been raised to feed visual information from flying drones (Nelson, 2006) or to feed information from infrared cameras to the tongue so as to not interfere with peripheral or night vision (Blakeslee, 2004).

Cochlear Implants

Since the prototype depends on some of the same technology as a cochlear implant an overview of the overlapping ideas is necessary. A cochlear implant is a surgically implanted device for people who are deaf. There is a small computer that takes in audio sounds from a microphone, and processes the information. The data is then sent to the internal device that activates the nerves in the inner ear. For normal hearing to work small hair cells normally activate these nerves. The problem arises that there are usually somewhere between 12 to 24 electrodes in the electrode array that are trying to replace the 16,000 hair cells (Chorost, 2005). Older cochlear implants only used 12 contacts because trying to put them any closer together could cause shorting between the electrodes. This was overcome by flashing the electrodes one at a time so that at any one time each electrode only had one active path to take (Chorost, 2005). The next discovery was the flash of multiple electrodes. When done in alternating pairs fast enough caused a tone between the two electrodes to be heard. In other words, flashing the existing electrodes faster creates a virtual electrode between them since the brain is not able to receive all the information.

The idea that a computer can deliver information faster than the user can perceive is used by the prototype by only allowing one electrical contact to be active at a time. Also the idea of flashing the electrical contacts to create virtual points has been used by the prototype. Instead of just a row of electrical contacts, the idea has been expanded from one dimension to a two dimensional matrix of electrical contacts that can create virtual points, or pixels, in between any of four congruent electrical contacts.

CHAPTER III

PROTOTYPE

This prototype tries to improve on previous research in two areas: in allowing for closer spacing of the electrical contacts and, secondly, the introduction of virtual pixels. Both are accomplished by activating electrical contacts individually for short periods of time as opposed to having all electrical contacts active at all times.

Being able to pack the electrical contacts closer together is based on only one electrical contact being activated at a time. The only place for the electrical charge to travel is from the electrical ground to the electrical contact. Unlike previous research, this should allow for the contacts to be as close together as needed. The reason for the contacts being the distance apart that they are currently is because of the handmade nature of the prototype.

The virtual pixels depend on the electrical contacts activating for very short periods of time. When multiple electrical contacts are able to activate fast enough, the brain only sees a single activation with a location between the two electrical contacts. This virtual point moves depending on the duration of the percentage of the total time that each electrical contact is activated.

Description

For use in the experiments, a prototype was needed to test the hypotheses. The following aspects will be discussed: software input and processing, microcontroller use, power control, and contact activation.

A regular USB "webcam" was used to capture the video coming into the computer. It was capable of much higher resolution and speed than what was required. Each frame was converted to grayscale. Since all participants were sighted, the grayscale weighting was the same used to find luminance for NTSC and PAL standards: 29.9% red, 58.7% green, 11.4% blue (Gonzalez, 2002; ITU 1992). Using the NTSC and PAL luminance weighting allows for the same color balance as the human eye. The contrast was then reduced to 16 levels to work with a microcontroller. This does not present a limitation because tactile nerve range of contrast is measured somewhere between three to five levels (Weiss, 2001).

Depending on the current needs of the test, the resolution was reduced to anywhere from a 12x12 pixels minimum to 16x16 pixels maximum. Each pixel is then recoded for its "X" and "Y" position and level of contrast and bundled into a packet that is sent through USB to the microcontroller. The microcontroller is connected through a different USB bus to limit traffic interference between the camera and microcontroller.

Figure 2 shows an overview of the layout of the prototype, and Figure 3 shows the entire haptic display built for the experiment. The microcontroller is a 40Mhz Microchip microcontroller using a PIC18F4550 chip. (See Figure 4.) It takes the packet from the USB and activates the correct wires. When the packet is received each group of two bytes is split apart. The microcontroller will first turn off the electricity to the mouthpiece through the enable bit on the multiplexers. The first byte designates the pins for the contrast levels. The next byte is written to the multiplexers for the "X" and "Y" coordinates. The electricity is then turned back on while the next set of numbers is set up. If the microcontroller is set to transmit virtual pixels, then each pixel will activate the contacts in a pattern.

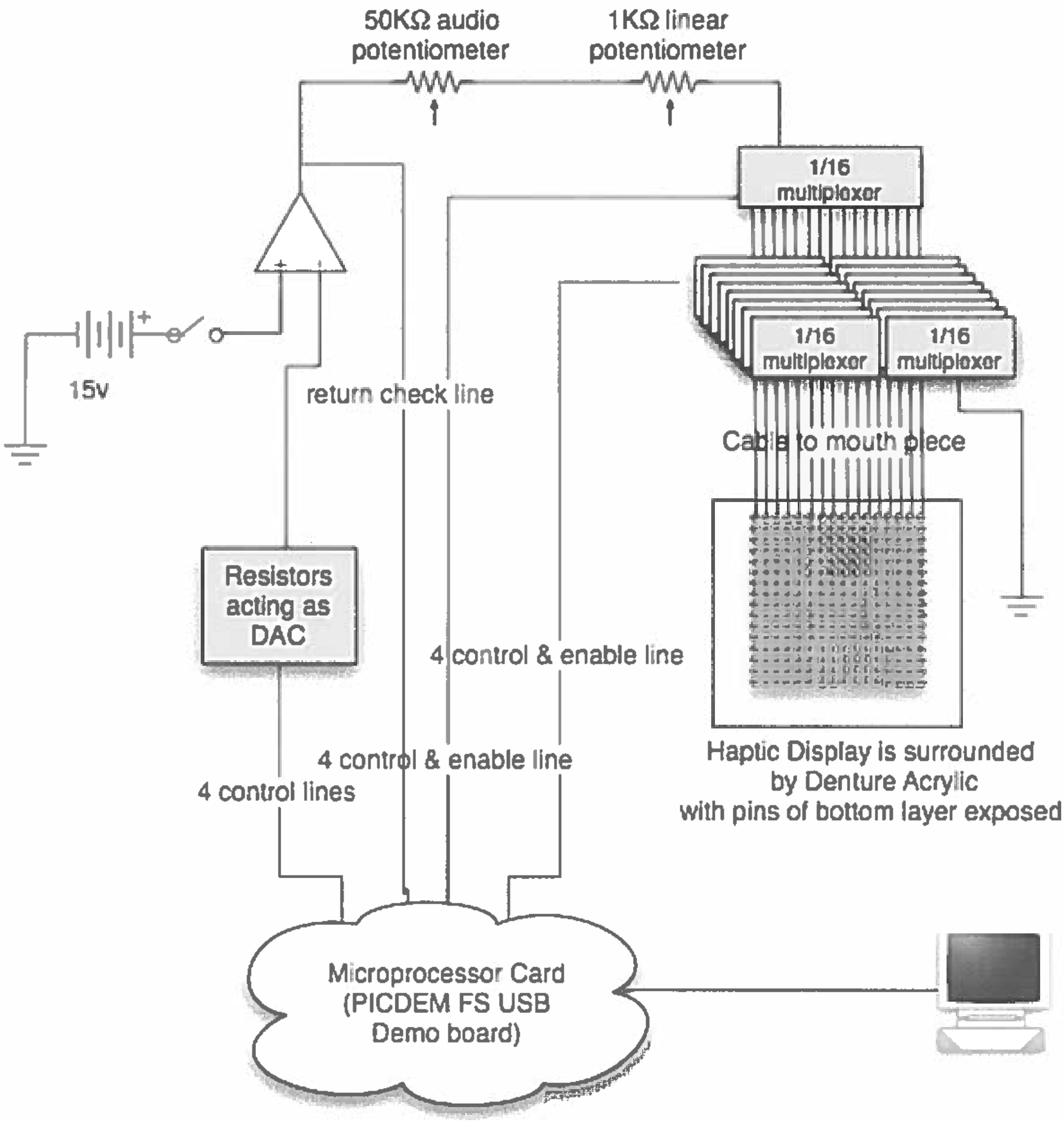

Figure 2: Overview of layout of prototype.

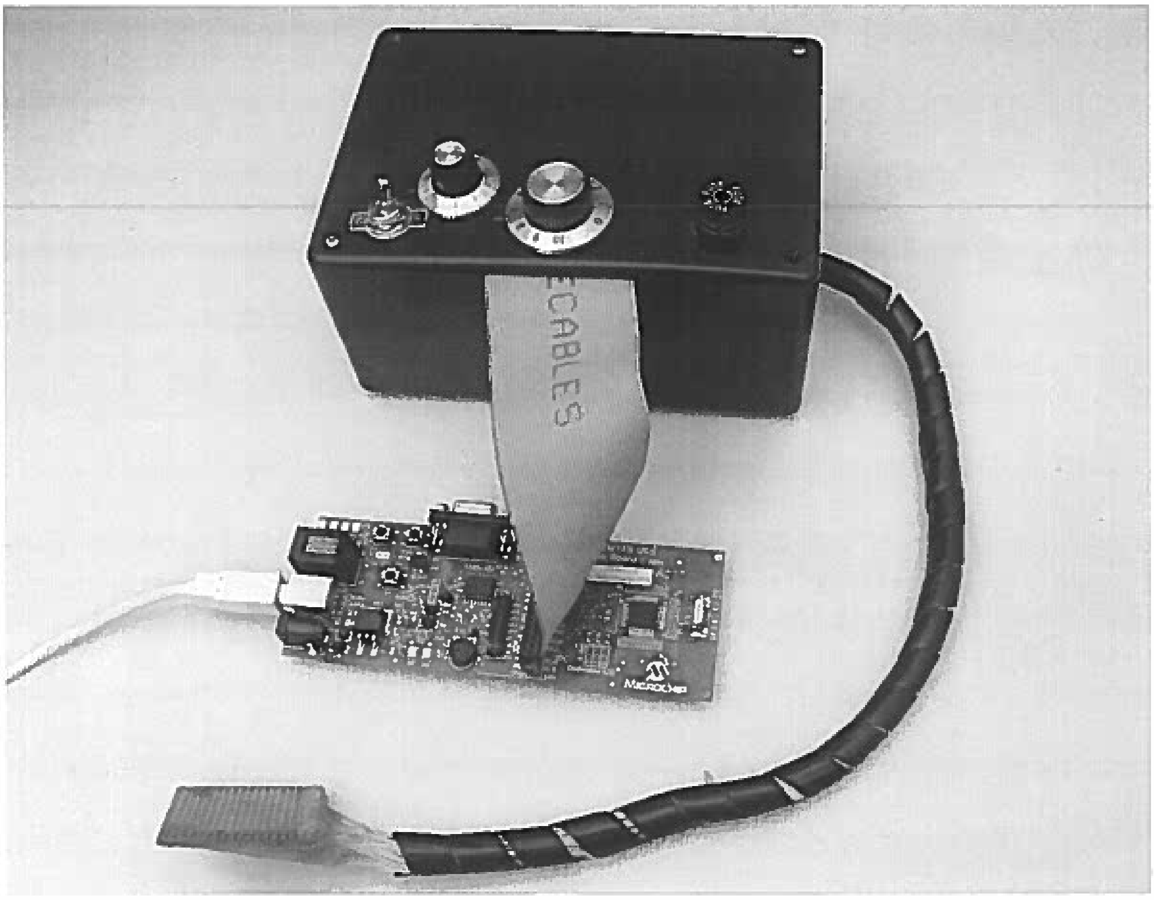

Figure 3: Entire haptic display built for experiment.

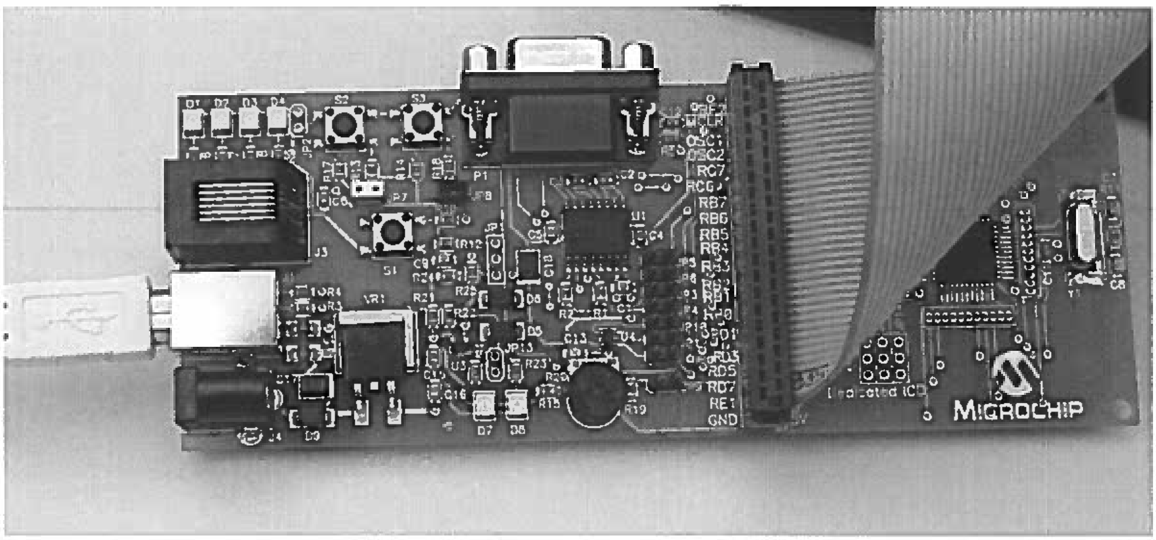

Figure 4: Microcontroller used for experiment.

Power to the mouthpiece is activated by the use of a series of resisters. The combined total of the power from the resisters is fed into an operational amplifier to amplify the voltage. The power then flows through a potentiometer to control the current that flows through the multiplexers into the mouth. Pins on the microcontroller control a series of multiplexers. (See Figure 5.) One multiplexer activates which row receives power. Each row has its own multiplexer that then activates the wire. With 16 rows and 16 columns on each row there are a total of 256 wires that feed into the mouthpiece. (See also Figure 2 and Figure 3.)

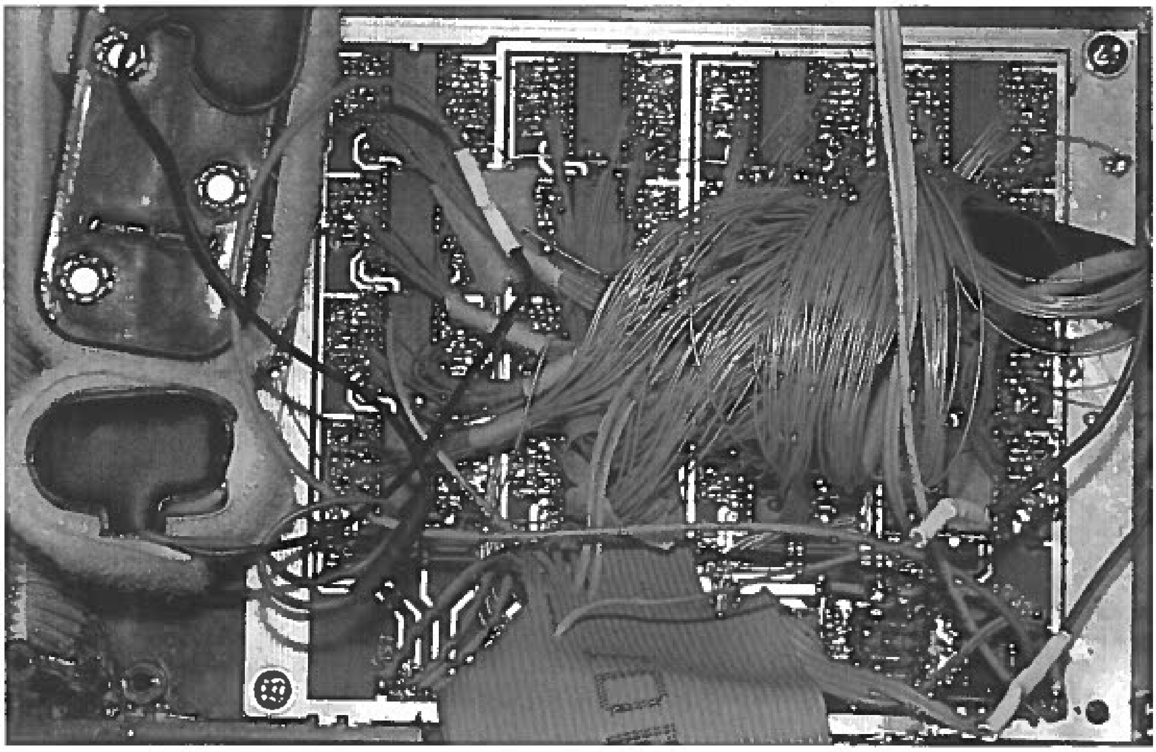

Figure 5: PCB board containing multiplexers and power circuits built for experiment.

The mouthpiece is a 16x16 array of points on a $40mm^2$ PCB. (See Figure 6.) The points use 0.062 inch spacing. Each wire is connected from the back to the front of the board by a via. (See Figure 7.) All contact pads on the front of the board are gold plated. The gold plated ground plating surrounds all contact pads. The back of the board and all via holes were covered with a denture base material to seal up all electrical connections and to protect participants from the chemicals in the RoHS solder.

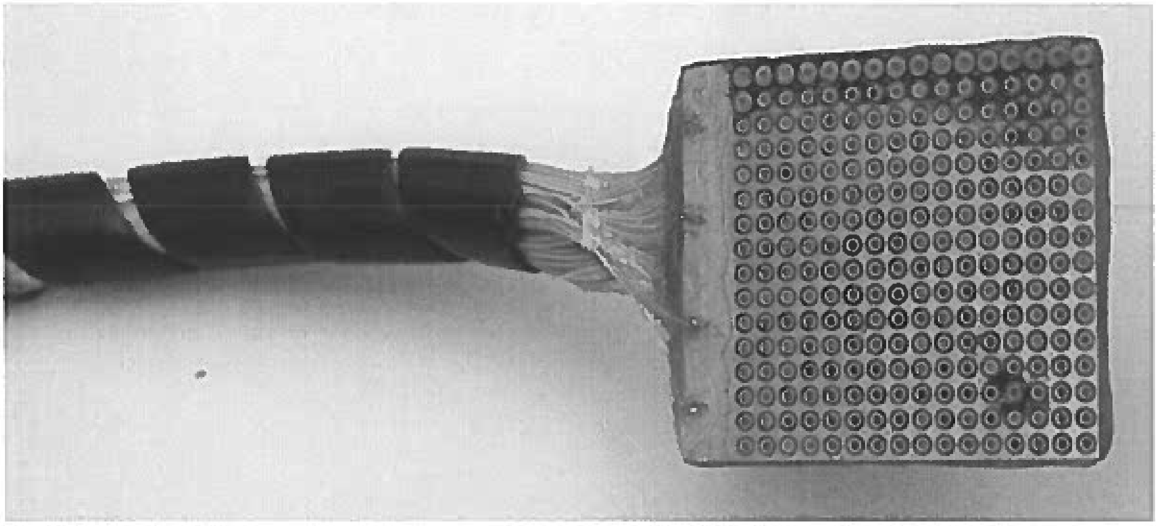

Figure 6: Front of mouthpiece built for experiment.

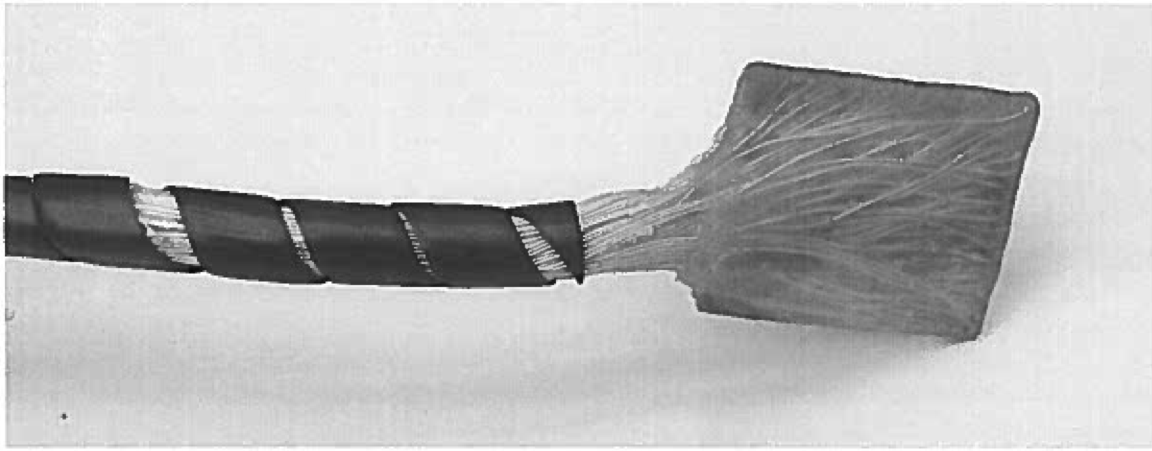

Figure 7: Back of mouthpiece built for experiment.

Pixel Density

Only one electrical contact is activated at a time ensuring there is no longer a problem of getting the electrical contacts too close together. The research focus is now to find out how many pixels could be put together. The danger of choking is a real hazard if something is placed too far back on the tongue. The circumvallate papille signals an end to the horizontal area of the tongue. Any farther back and choking is risked (Zemlin, 1998). The average usable area on the tongue is 35.3mm length and 44.2mm breadth (Oliver, 1986). Even without using the entire tongue it makes it the largest grouping of nerve endings. If the device placed in the mouth was made to be 30mm by 40mm with actuators every 0.24mm to avoid the Moiré effect (multiplying .62 by 2.5), it is possible to have a matrix of 166 x 125 for a total of 20,750 points of interaction. For reference most current color cellular phones or black and white PDA's have a screen resolution of 320 x 240.

This prototype, because of its hand-built nature, is not able to reach these levels of pixel density. However, current machine production of LCD screens produces a similar material that could be used for a haptic display. The current pixel density of LCD screens is vastly smaller then what is being proposed, so this technology is possible today.

Virtual Pixels

For human skin, the speed of reception increases with the depth of the receptor cell within the epidermis and the dermis. This means that the higher the frequency of stimulation, the stronger the signal would need to be, either harder pressure or higher electrical current. Since it is deeper within the dermis, there is also less resolution possible for the faster two cells. After analyzing the different types of cells, it can be shown that information transmission can only be sustained at 40 Hz with short bursts of faster more general impulses (Goldstein, 2006). At this speed the Meissner cells in the skin are high enough to get good temporal resolution, but also fast enough to respond to textures, or in this case information from the mouthpiece. For the prototype built, anything transmitted faster than 40 Hz and slower then 500 Hz will cause the somatosensory system to start to blur information together.

This information and what is known about cochlear implants is what this experiment of virtual pixels is based on. The idea is that as long as the length of response is the same for each pixel, the firing of the contacts determines where the virtual pixel is sensed. If the length of time were altered for different pixel locations, then certain pixels would always have a lower contrast. The algorithm avoids this by using the same number of electrical contact firings for each virtual pixel. This ensures the consistency in length for each virtual pixel.

For each virtual pixel there are four surrounding electrical contacts that need to be fired in the correct pattern:

$$F = (2 + 2 * P) - (H + V)$$

- F=total firings of electrical contact where the electrical contact is one of the four surrounding contacts.
- P=number of virtual pixels being represented.
- H=horizontal distance in pixels the virtual pixel is from the electrical contact.
- V=vertical distance in pixels the virtual pixel is from the electrical contact.

The block of code to implement this algorithm is show below:

```
block = P + 1;
totalFlashes = (2 + (2 * P));
topLeft = totalFlashes - (H + V);
topRight = totalFlashes - ((block - H) + V);
bottomLeft = totalFlashes - (H + (block - V));
bottomRight = totalFlashes - ((block - H)+(block –V));
flash = topLeft + topRight + bottomLeft + bottomRight;
while(flash > 0){
```

```
        if(topLeft > 0){
             FlashTopLeft();
             topLeft = topLeft - 1;
             flash = flash - 1;
        }
        if(topRight>0){
             FlashTopRight();
             topRight = topRight - 1;
             flash = flash – 1;
        }
         if(bottomRight>0){
             FlashBottomRight();
             bottomRight = bottomRight - 1;
             flash = flash – 1;
        }
        if(bottomLeft>0){
             FlashBottomLeft();
             bottomLeft = bottomLeft - 1;
             flash = flash – 1;
        }
}
```

To give a better idea, Figure 8 illustrates how the algorithm would fire in a one virtual pixel situation for representing a pixel in the top center location. The gray dots represent electrical contacts with the white dot showing the virtual pixel location. There are eight possible pixel locations with V showing the pixel that is being represented. Their firing order would be: 1,2,4,3,1,2,1,2.

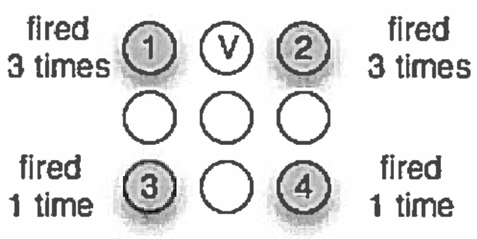

Figure 8: Firing number for a virtual pixel in the top center.

To show how the same algorithm works for larger cases, Figure 9 is given to illustrate when transmitting 3 virtual pixels between electrical contacts. The largest squares represent all virtual pixels possible within four congruent electrical contacts. Each small box of shows the number of firings needed from each of the electrical contacts to represent a virtual pixel in that position. The boxes that are in each corner of the larger square represent the virtual pixels that would directly cover an electrical contact. The firing order for any virtual pixel would be in a clockwise rotation starting in the top left number for each group of four numbers. The firing would continue with one firing of each electrical contact until all contacts have fired the correct number of times.

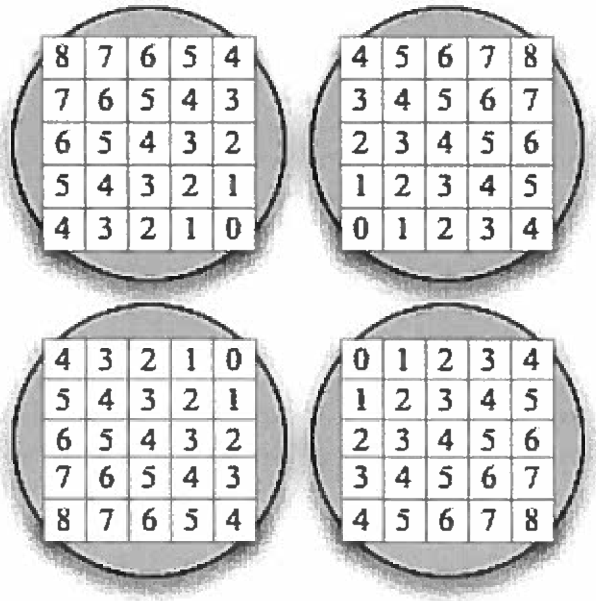

Figure 9: Firing order when using 3 virtual pixels.

Using this algorithm for creating virtual pixels no longer puts the burden on making smaller hardware. Instead the limitation would be back to the amount of information that could be perceived through the skin, or the amount of information that could be sent. This would depend on which amount was smaller. As with cochlear implants, the balance would need to be found between how many virtual pixels could be used and the number of electrical contacts needed to transmit the most information that could be perceived.

CHAPTER IV

EXPERIMENT

After building the prototype, testing with human participants was needed to test the ideas that have been implemented in the prototype. This prototype was developed to build off of previous research and the only way to validate the prototype is to test it in controlled circumstances to verify it is capable of what it attempts. The experiment was set up to test participants below, at, and above estimated ability of human perception to find the limits of the prototype, human perception, or both.

Research Questions and Hypothesis

The first and most basic hypothesis in this experiment is that the brain will interpret a pulsing signal for the spatial data transmitted to each electrical contact as if it were transmitted to all electrical contacts simultaneously, like previous research. The second hypothesis is that increasing the number of electrical contacts will allow for better resolution of the information interpreted by the brain. The final, most ambitious, hypothesis is that using a pulsing signal for spatial data transmitted to each electrical contact in an alternating pattern will give the sensation of virtual pixels that are perceived between the electrical contacts.

In addition to hypothesis testing, doing this experiment it is hoped to validate previous research that the visual cortex can process visual information received through the haptic display. Part of the experiment is to try to find out if the amount of information being transmitted to the skin is already too much or if more information can be perceived, and if so, how much more information is understood as more electrical contacts are added. There is also the need to find if pulsing alternating electrical contacts will produce the sensation of "virtual pixels" that are perceived between the electrical contacts there is also the hope that this experiment will be able to find the maximum number of virtual pixels that can be perceived between electrical contacts before there is no more resolution gain.

With the success of this technology there is the possibility of long-term use of these types of devices. Because of this, one of the goals of this experiment is to record anecdotal evidence on fatigue and use of the haptic display. Also, this will be seen as prostheses used for more then just symbol recognition the experiment hopes to find the speed of recognizing unprompted objects as opposed to recognizing symbols from a given set.

Experiment Description

This experiment is split into five distinct areas: training, letter size configuration, pixel density, virtual pixels, and object recognition. All activities are done in the same area with small changes to the setup as needed. As shown in Figure 10, the administrator controls which test is run from their computer.

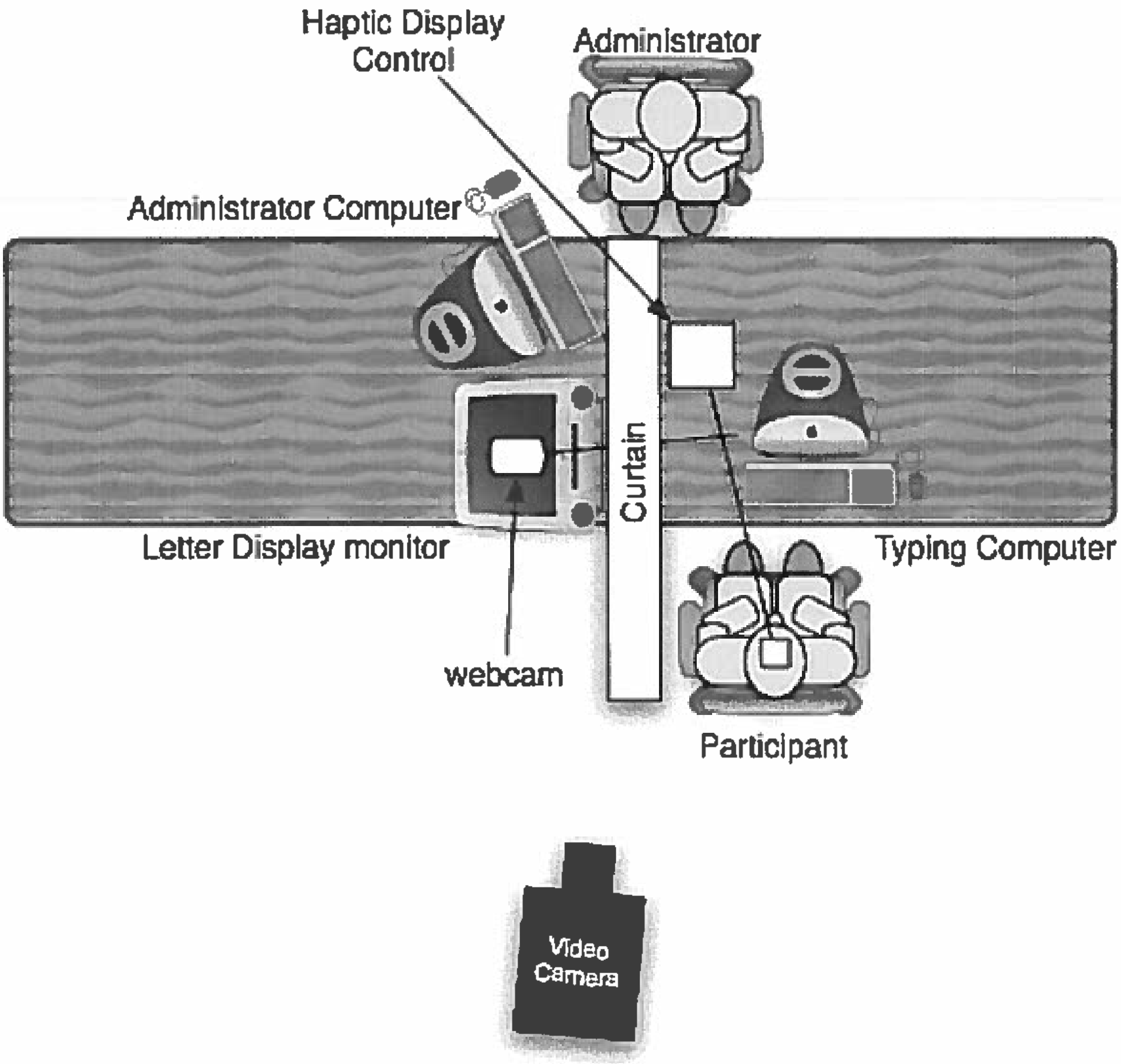

Figure 10: Experiment setup.

The participant has a keyboard and mouse to click or type in their response on a separate computer. A curtain separates the participant from another monitor that displays letters and the answers. This other monitor is lying on its back with the screen pointing straight up.

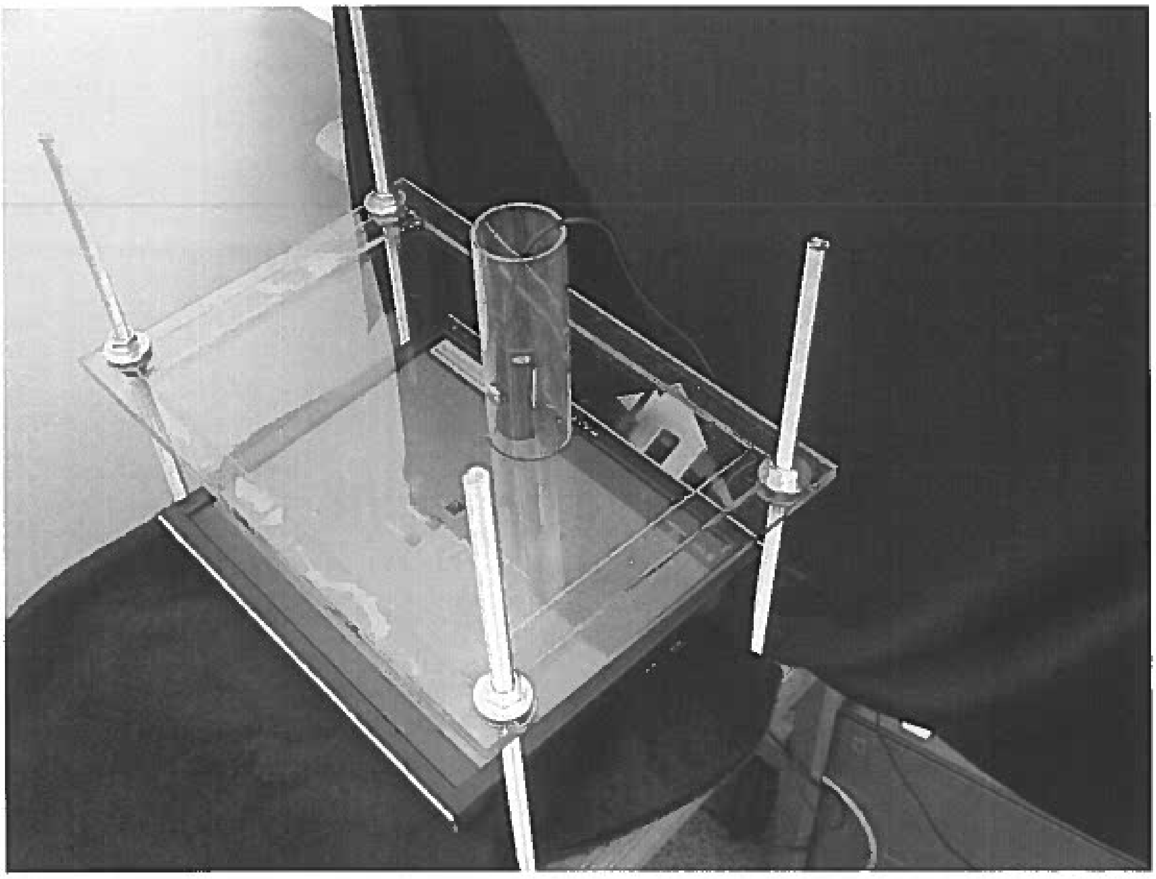

Figure 11: Stand holding camera above monitor.

The haptic display runs from the participant's mouth to their computer. Also connected to the computer is a small video camera commonly known as a "webcam". (See Figure 11.) The webcam will rest on a clear frame that retains the webcam directly above the letter-viewing monitor. Participants will be able to move the webcam within the area of the frame. Previous research has shown when subjects were quizzed on character recognition their accuracy went from near chance if the symbol was stationary to 100% when the subject was allowed to move the camera over the symbol (White, 1970).

All documents given to participants are included in the Appendices. The participant is first given the safety screening (Appendix B) verbally, then is given the consent form

(Appendix A) to read and sign. A handedness test is then given (Appendix D), and the tests are set-up with the participant to type with their dominant hand and move the webcam with their non-dominant hand. All experiments are described in the Procedure section.

To make sure the participants' experiences are similar, the same contingency protocols were developed. If the participant's eyesight was insufficient to read any material, such as the consent form, then all material will be read to them. If the participant stopped and did not want to continue, the administrator would attempt to present the exit survey; and then the participant would be paid. If the participant experienced numbness of the tongue or a metallic after-taste, then saltine crackers and water would be offered. If the participant felt any pain from the electricity then the experiment would end. In all cases participants are paid.

The haptic display used for the experiment will be sanitized between experiments in 3.4% glutaraldehyde, a solution used by dentist's offices to sanitize their equipment, and then be allowed to dry completely to allow all chemicals to evaporate. Also, if the participant requests more information because of the novel nature of the experiment, then the document titled "extra information", included in the Appendix, would be given to them to read.

Participants

Participants are chosen from people that have responded to advertisements or that were familiar with this project. Screening was done over the phone or by email using the screening form. All participants needed to have sufficient sight to see the squares during the training exercise. Because of this requirement, participants who were blind could not be used for this experiment. The only other limiting factor for the participants was who could fit into the schedule to be tested. All participants either were students or worked for the university.

Procedure

There are five sub-areas of the procedure: training, letter size configuration, pixel density, virtual pixels, and object recognition.

Training Exercise

The goal of this portion of the experiment is to teach the participant to recognize the stimulus presented from the haptic display. The minimum hope is they will be able to recognize when the large spot is gone over with the camera. Possible latent learning of letters could also happen with each box being lettered. The aspects that are being measured: time to respond, and number of incorrect choices. The expected outcome is that the participant's time for response should improve with training.

The participant is presented with a screen with lettered green squares. (See Figure 12.) A dot moves under the squares. With their hand through the curtain the participant controls the webcam over another monitor with a similar layout of square. (See Figure 13.) The dot on this monitor moves above the squares. The participant's task is to choose the square that the dot ultimately stops under. As the subject gets answers correct, the speed of the dot moving under the squares increases until the dot is placed under a square randomly. The subject starts out with 2 x 2 grid of squares on a screen for a total of four squares. After choosing four squares in a row correctly at random placement speed the number of squares will be increased to 16 squares in a 4 x 4 arrangement. Speed starts over again moving up to random placement with the same requirement of choosing four correctly in a row ending the training period.

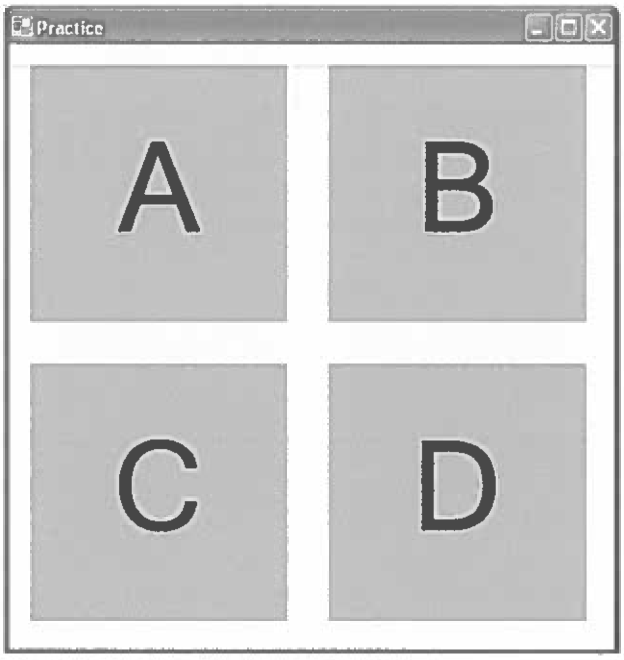

Figure 12: 4-box view the user sees on typing computer.

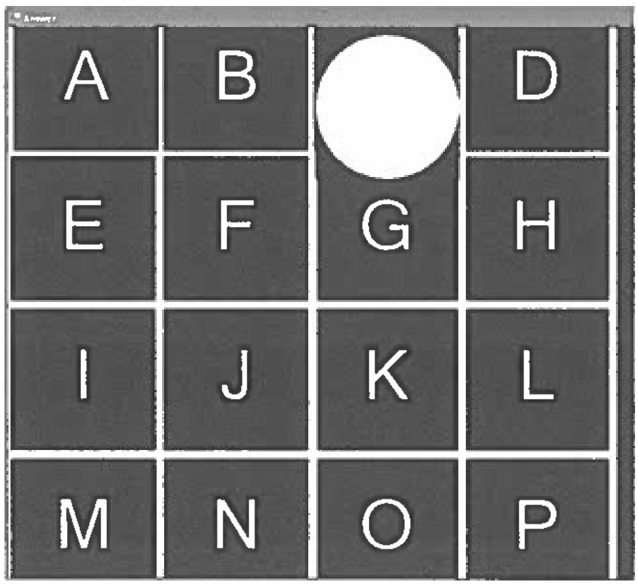

Figure 13: 16-box view that is displayed on the letter display monitor.

When the dot stops moving the boxes turn from green to red to signal a response. A timer then measures how long the participant takes to click on one of the squares. After the participant clicks on a square the title of the window changes to tell them if their response was correct or not and displays the correct answer.

Letter Size Configuration

The goal of this portion of the experiment is to determine how large a letter must be to be recognized. There is also a training aspect to this portion to allow the participant to start recognizing from the set of letters. The aspects that are being measured: time to respond, number of incorrect choices, letter choice, and size of letter. The expected outcome is the participants will be able to perceive the letter after it reaches a large enough size.

On the letter display screen white letters are presented with a black background starting with a 120 point Times New Roman letter. (See Figure 14.) The participant has a window on their monitor that displays the feedback from the letter they typed and if they typed the correct letter or not along with the correct answer. There is a time limit of two minutes for each choice with a timeout considered an incorrect answer. Time left is also shown in the feedback window.

On a screen under the webcam a black screen is presented with a white letter in the middle. For each wrong choice there is a 20-point increase in the size of the letter. After two correct choices this stage ends and the size of the letter is saved as a reference size for the rest of the experiments. All letters are displayed as capital letters. Letters were chosen that had three main strokes to create them: A, B, F, G, H, K, N, Y, and Z.

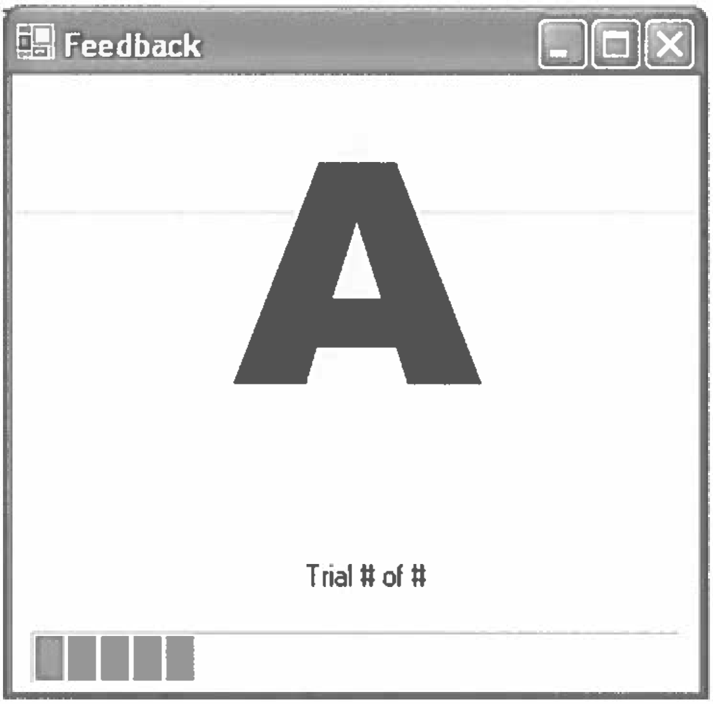

Figure 14: Window used for letter size configuration, pixel density, and virtual pixel tests.

Pixel Density

The goal of this portion of the experiment is to determine the amount information that is recognized by using more electrical contacts. The aspects that are being measured: time to respond, number of incorrect choices, letter choice, and size of letter. The expected outcome as the number of electrical contacts is increased is that letters will be perceived at a smaller font size and be perceived at the same font size faster.

The grid on the haptic display will increase and decrease the number of pixels presented in a random order ranging in size by one electrical contact each from a 12x12 grid to a 16x16 grid on the haptic display. The haptic display will change the number of pixels each time the participant gives a response. The same feedback window will be present to let the participant know what they typed and the correct answer if they choose incorrectly. (See Figure 14.) The same two-minute time limit is in effect. The computer will track the time between when the letter is displayed and when the letter is typed, along with letter size and number of electrical contacts used. Three random letters will be presented per pixel resolution setting. Three letters will be smaller, three letters will be the same size, and two letters will be larger. The same letters will be presented as in the previous portion of the experiment. This provides for a total of 40 letter tests.

Virtual Pixels

The goal of this portion of the experiment is to determine the amount information that is recognized by adding extra virtual pixels. The aspects that are being measured: time to respond, number of incorrect choices, letter choice, and size of letter. The expected outcome as the number of virtual pixels is increased is letters will be perceived at a smaller font size and letters at the same font size will be perceived faster.

The settings for virtual pixels will be one, two, or three virtual pixels in-between each of the electrical contacts. The same feedback window is available with the same two-minute time limit. (See Figure 14.) Based on the reference size of the letter from the letter configuration test, eight random letters will be presented for each of the virtual pixel settings; two at the same size, then one each getting smaller in size from the reference size. The same letters will be used as in the previous test. This allows a total of 24 tests.

Object Recognition

The goal of this portion of the experiment is to determine if the participant will be able to recognize unprompted objects. Since these items are no longer part of a defined set the participant will need to know the item instead of recognize it. The aspects that are being measured: time to respond, number of incorrect choices. The expected outcome is that using the optimal settings found from the previous two experiments, the participants will be able to correctly recognize objects.

For this last test the letter display monitor will be moved out of the way along with the stand. A large piece of black felt will be laid out on the table to dampen any sounds of the objects as they are placed down and to absorb extra light produced by room lighting. The everyday objects being used are: hair comb, wrist watch, tube of toothpaste, doll, fork, coffee cup, scissors, sunglasses, door key, and keyed padlock. (See Figure 15.) They will be placed one at a time on the table by the presenter in a random order printed out by the computer. The participant will use their webcam to move around the object. A plastic ring has been placed around the webcam to prevent accidental hand to object collisions that could give hints to what the object is. (See Figure 11.)

Timing for guessing as well as answers will be recorded with a separate video camera. The participant will take the haptic display out of their mouth for a guess and will be told if it is correct or not. They will get three guesses for each object. The participant has 10 minutes to try to guess as many objects as possible presented to them.

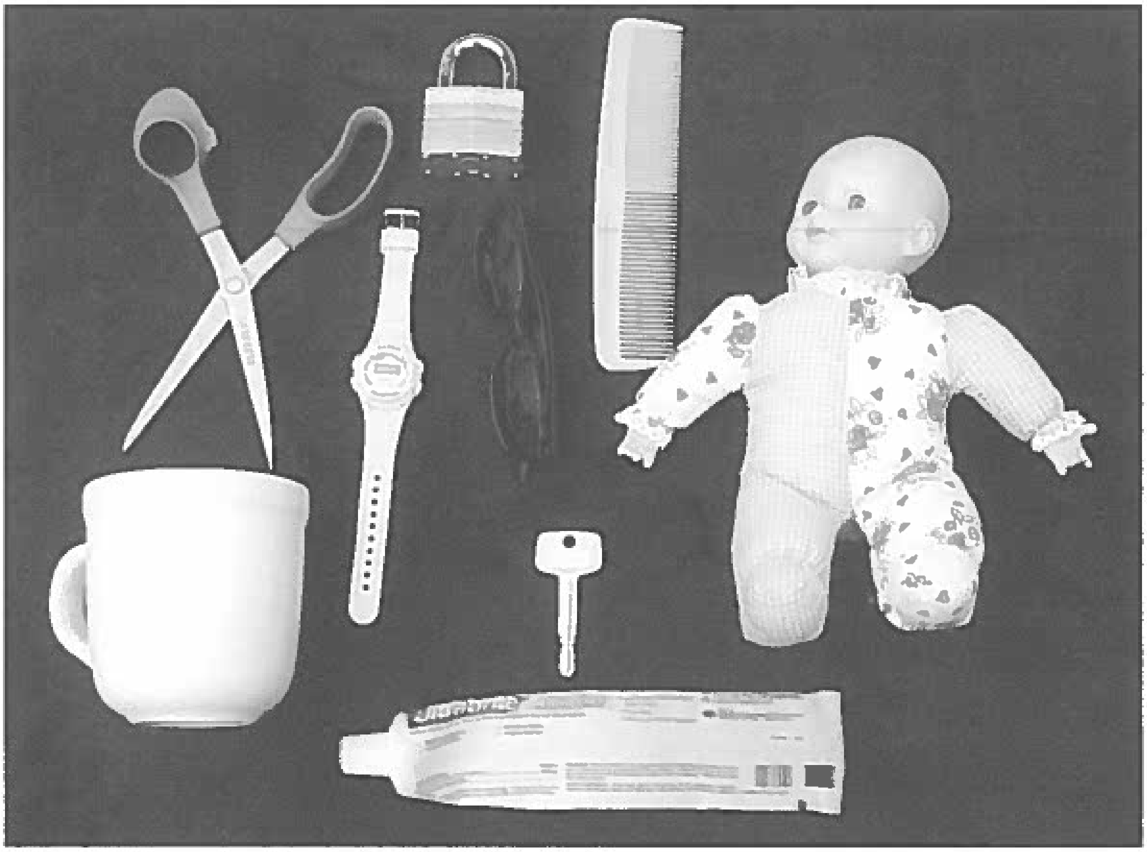

Figure 15: Objects presented for recognition.

Experimental Environment

The experiment was done within a small room in the computer science building on the university campus. (See Figure 16.)

Figure 16: Experiment environment.

Design and Analyses of Data

The data that is collected from the practice exercise and letter size configuration test will verify the first hypothesis, that the brain will interpret using a pulsing signal for the spatial data transmitted to each electrical contact as if it were transmitted to all electrical contacts simultaneously. If the participant is not able to make sense of the information that is being received from the haptic display they will not be able to guess enough correct choices within the time limit. Other data colleted during these portions of the experiments are anecdotal in nature but will be able to show the rate at which the participants were able to learn how to use the haptic display.

Data collected from the pixel density portion of the experiment is to verify the second hypothesis, increasing the number of electrical contacts will allow for better resolution of the information interpreted by the brain. The size of the letter will be correlated with the number of pixels in the matrix being used. Since the size of the lens is known for the webcam, with this information it should be possible to determine the level of sightedness similar to previous research was able to determine their device achieved the equivalent of 20/860 sight.

Data collected from the virtual pixel portion of the experiment is to test the final hypothesis, using a pulsing signal for spatial data transmitted to each electrical contact in an alternating pattern will give the sensation of virtual pixels that are perceived between the electrical contacts. There was enough information being transmitted during this experiment that a maximum should be found in resolution understood by skin.

Data collected during the object recognition portion of the experiment is mainly to make sure that the participants are noticing unique aspects of the information that they are receiving instead of just recognizing objects from a given set. Any correct identification would be considered quite significant.

Results

None of the participants in a pilot test were able to get past the training exercise portion of the experiment. Time limits used in this experiment are similar to what previous research has shown to work. Even given twice the amount of time allotted and allowing them to redo the training still could not produce results. Choices made by participants were no higher then chance. Participants reported not being able to understand what was being sent to the haptic display. The lack of results for the pilot test led to less then the original number of people being tested. Out of 12 planned participants only three people were tested.

Participants were able to feel the electro-stimulation to their tongue. They reported feeling a difference when the webcam was pointed at a bright area and a dark area but could not pick out the difference on their own.

Discussion

With none of the participants being able to perceive the information that was being sent to them in any usable manner this points to one of four likely outcomes. First the most obvious one would be a malfunction in the prototype that was built. The hardware was tested with an oscilloscope to verify that all multiplexers being used were working with the operational amplifier and able to output correctly so this should not be a cause. The next most probable cause is the first hypothesis is wrong. This also is probably not the cause. The research that the prototype is built from strongly mirrors the timing of cochlear implants so it most likely is possible to use strobing electrical contacts to send information.

The most likely cause is something that happens to many large projects. There is a bug somewhere in the system. Many problems were encountered building the prototype that had to be worked around or optimized to allow. Any one of these issues could be the culprit that only time and code reviews would be able to find.

The computer was running in the gigahertz range, the microcontroller at 40 megahertz and the operational amplifier was being pushed to its limit at 3 megahertz.

Keeping communication synchronized among them proved to be a major problem and possible cause of failure.

Another possible issue was the volume of data required. When transmitting virtual pixels, even for only one virtual pixel, the amount of data doubled and strobing the electrical contacts increased 8 times. There were many revisions to the data being transferred to compact it as small as possible and for the microcontroller to process it as fast as possible. It is possible that a bug still remains from the many revisions.

CHAPTER V

CONCLUSION

There is disappointment with none of the hypotheses being supported. However, there is still a lot to be learned from this prototype and experiment. As with any large project, many things can go wrong. In this case, most likely a software problem, is the cause of not being able to get more interesting data.

Summary

The prototype was built successfully along with the software for the test. The experiment created was sound. However, none of the hypotheses could be supported by the data collected. This could have been caused by one of the many problems encountered while building the prototype.

Future Work

The most obvious future work for this prototype is for it to work. Tracking down the bug that will allow for a more definitive answer on the hypotheses is the first priority. Beyond that, if the hypotheses hold true then it opens up new areas to explore such as color or stereo information being transmitted.

An obvious need is for transmitting data to the mouthpiece wirelessly. Having something in the mouth without being able to close the mouth is not acceptable for normal use. This would require much smaller wiring, which would be possible if it were known that the hypotheses stated were correct. If virtual pixels were possible, then it would allow for less electrical contacts, and therefore a smaller size.

Problems

There are some problems that could arise from using the tactile stimulation for vision. As stated earlier if a tongue device is used there is a possible choking hazard because people that have used the tongue device have stated that they forgot that they had it in their mouths (Weiss, 2001; Blakeslee, 2004; Abrams, 2003). A wireless version has been proposed in previous research. Were it created, this problem could be handled by the bite plate, an under the tongue design, or by a design that is too large to fit down the throat.

With the use of a tongue haptic display there are sanitary issues. A lot of people would have an issue of placing something inside their mouth repeatedly. The possibility of showing an image to someone else would also be reduced to near zero. If a bite plate were used then it would need to be adjusted or created for each specific user.

If this were to be used for navigation then it would be expected to be in use for long periods of time. There have not been studies about what using the nerve endings to their maximum input ability might do. It is not known how long a tactile display could be used before over stimulating the nerve endings until they became numb or if they would be over stimulated at all. Also this leads to the next problem if the tongue was used for a tactile display for long periods, would the sense of taste be diminished from over work? The tongue would also not be as mobile to allow for wetting the lips.

New Uses

A possible application for a haptic display is for use in multi-tasking environments.

When most of the current computer user interfaces are designed and tested it is assumed that the user is giving 100% of their attention to the attempted task. In addition the assumption is made that the user has 100% of their facilities to devote to the needed task. It is better to think that everyone will sooner or later be in a situation that does not allow him or her to devote 100% of their attention at 100% of their ability either through old age, a disability or a demanding situation (Newell & Gergor, 1997). In these situations it is best for the user to receive information in a multitude of ways so that the sense that is being taxed by the current situation or disability will not have to split task processing. The more senses that are used to convey information to the brain the less any sense one is overwhelmed. This leads to more and better comprehension possible with less error (Schmorrow & Kruse, 2004). The most obvious use of a tactile display is when vision is needed for other actions such as when driving or walking while using a PDA.

Another possible use of the tactile display is to diminish the limitations of a visual display. There has been a lot of debate about why the user interface is stuck with two dimensions and cannot make the jump to displaying the third dimension. Currently a visual display gives incorrect information through: inappropriate focus cues, pixelization, and inappropriate motion parallax during head movements (Ernst, 2002). If the tactile display was used to display a separate angle 90 degrees from what is shown by the visual display then it would allow the user to receive more information then what is displayed on the retina. The extra information such as a top down view would allow for more spatial cues. Without them looking for hidden objects in the visual display could easily confuse the user.

Current technology uses binocular vision to try to allow the user to see the third dimension. However, for the illusion to seem real visual feedback from outside the visual display needs to be shut out. Without the external visual cues many people feel nausea because their sense of balance does not agree with their sense of sight. The haptic display with current technology has already been shown that it can help subjects to "see" their own sense of balance using accelerometers and mercury levels (Blakeslee, 2004). More studies would need to be done but the haptic display could also be used to try and override the subject's sense of balance enough by conveying the sense of orientation that is consistent with the binocular visual display. This could be used for games and information visualization where this problem is most prevalent.

Conclusion

It is obvious that this field needs more research. The possible benefits from products mentioned within this thesis make science fiction seem possible. The problems arise, as shown by the experiment, that complex systems such as these can have many problems that prove hard to solve. However, this thesis shows the need for research because of the great possibilities from using this technology in the many areas that it is applicable.

APPENDIX A

CONSENT FORM

Title: Evaluation of a Haptic Tongue Display

Principal Investigator:
Mark Bailey, 232 Deschutes Hall
Phone: 541-346-4469
email: mbailey@cs.uoregon.edu

Purpose:

This project is designed to increase our understanding of the interaction between the brain and the sense of touch. Previous research has shown that the tongue has the highest concentration of nerves for the sense of touch. Using the tongue there has been high enough sensitivity to give a sense similar to sight given the correct circumstances and equipment.

Procedure:

The haptic display is a small device with a grid of electrical contacts on it. This device will rest on you tongue. From this device a small cable runs to the computer where it receives video information. The hope is that the brain will be able to recognize information sent to it through the skin.

You will be asked to place this small device called a haptic display on your tongue. After a training session on how to use the haptic display you will be asked to try to identify letters of the alphabet and everyday household items without the use of vision.

A curtain will be set up between you and the objects to identify. With one hand through the curtain you will be able to control the camera. When letters are recognized you can type them with your dominant hand on the keyboard. You will have control of the power switch to the device to end the project any time you feel discomfort.

There are three sessions with breaks in between each session. You will be asked questions about your experience with the haptic display between sessions. More specific information will be given to you at the beginning of each session. You can ask questions at any time, including prior to signing this form. A full description of the study, or protocol, is attached as an addendum to this form. Likewise, you will be debriefed following your participation.

Risks and Discomfort:

The tasks you will be asked to complete can cause fatigue. Since there is a high level of concentration there is a chance of a headache. The visit should not take longer than 2 hours.

From previous research done in using similar devices participants have reported that they feel a small tingling on their tongue. Some have reported it feels similar to "Pop Rocks" candy on the tongue. Most participants have said that the tingling sensation is no longer noticeable once spatial information is being recognized.

Although the levels of voltage being used are not any higher than some batteries, some people are sensitive to low levels of electricity. Braces, or facial and oral piercings cannot be in place during any of the sessions. Anyone with a history of seizures, stroke, heart problems, and migraines, along with possible expectant mothers, has an increased level of risk and will not be allowed to participate.

No part of this project's goal is to cause any kind of any pain. If at any time any pain is felt the project will stopped completely if it is your wish, or the problem corrected so you no longer experience pain before the exercise is continued.

Since you will be putting something in your mouth that contains metal there is a chance you will have a metallic after-taste. There are saltine crackers and water to help get the taste out of your mouth. Stimulation of the tongue can cause temporary numbness similar to that caused by eating spicy food. This sensation will pass and saltine crackers and water are available to help.

The display itself is sanitized in between each use so it is sterile. The plastic case around the display is the same plastic used for dentures and the metal contacts on the device are made from silver similar to tooth fillings, so nothing should pose problems.

Benefits:

You may or may not personally benefit from participating in this study. However, by serving as a participant, you may contribute new information that may benefit the sciences and people in the future.

Compensation:

You will be compensated at the rate of $20 for the session.

Alternatives:

You may elect not to participate in this research study. **You have the right to withdraw from participation at any point without penalty.**

Confidentiality:

All of the records and data from your participation will be kept confidential. Your data will be rendered anonymous by assigning it a number and removing your name immediately after it is collected. The results of your participation in this study may be used for publication or for scientific purposes, but neither your name nor your identity will be disclosed unless you give separate, specific consent to this, or unless required by law. The research records for this study may be reviewed by a funding agency, such as the Department of Health and Human Services or by the Food and Drug Administration or other regulating agencies. According to Oregon Law, suspected child or elder abuse must be reported to appropriate authorities.

Costs:

None.

Liability:

If you are physically injured because of the project, you and your insurance company will have to pay your doctor bills. If you are a UO student or employee and are covered by a UO medical plan, that plan might have terms that apply to your injury.

Participation:

Your participation in this research is entirely voluntary. You do not have to participate and you may withdraw at any time without prejudice to yourself. We may discontinue your participation from this research study at any time if we feel it is in your best interest. **In the event of early withdrawal you will receive full compensation for the session.**

Mark Bailey is a graduate student at the University of Oregon who is specializing in Human Computer interaction. Mark Bailey is available to answer any questions you might have. His office is located in 232 Deschutes Hall or he can be reached by phone at 541-346-4469 or email: mbailey@cs.uoregon.edu

Sarah Douglas is the Academic Advisor for this experiment. Her office is located at 343 Deschutes Hall and she can be reached at 541-346-3974.

If you have any questions regarding your rights as a research subject, you may contact the University of Oregon, Human Subjects Compliance Office, 5219 University of Oregon, Eugene, OR. 97403. 541-346-2510.

You are welcome to ask questions about the study at any time and you may ask to discontinue testing at any time.

You will receive a copy of this consent form upon request.

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you may receive a copy of this form, and that you are not waiving any legal claims, rights or remedies.

______________________________ ________________

Participant's Signature Date

______________________________ ________________

Print Your Name Your age (years & months)

This session will be videotaped for confirming that the same protocol was used consistently. The camera will not try to record your face to help with privacy.
By signing this video consent form you acknowledge that you have received an adequate description of the purpose and procedures for videotaping sessions during the course of the proposed research study. You give your consent to be videotaped during participation in the study, and for those videotapes to be viewed by persons involved in the study, as well as for other professional purposes (faculty advisor ensuring exercise was conducted correctly). No one not directly involved with this experiment will view the videotapes.

I understand that all information will be kept confidential and will be reported in an anonymous fashion, and that the videotapes will be erased after the study has been completed. I further understand that I may withdraw my consent at any time.

Print Name____

Signature of participant________________________________ Date____________

APPENDIX B

PARTICIPANT SCREENING FORM

Read aloud to participant:
I'm going to read a list of questions about conditions you may have which will let me know if you are eligible to participate in the study. I do NOT want you to answer any specific question. Instead, after I ask the entire list of questions, I will ask if any of the questions apply to you. If any question does apply, you will not be eligible to be in the study. If you are uncertain about anything or need anything repeated please ask at any time.

1. Have you ever had any adverse reaction to electricity?
2. Do you have any nervous ticks or muscle spasms?
3. Have you ever had a stroke?
4. Have you ever had any head injury?
5. Do you have any metal in your head? (such as shrapnel, surgical clips, or fragments from welding or metal work.)
6. Do you have any implanted devices?
   (cardiac pacemakers, medical pumps or intracardiac lines)
7. Do you suffer from frequent or severe headaches?
8. Have you had any other brain-related condition?
9. Have you ever had any illness that caused brain injury?
10. Are you taking any medications?
11. Do you have any allergies to plastics, metals, or any other artificial substance?
12. If you are a woman, is there any chance that you are pregnant at this time?
13. Does anyone in your family have epilepsy?

14. Have you had any recent dental work or oral surgery?

Do you need further explanation of this experiment and it's associated risks?

APPENDIX C

FATIGUE SURVEY

Read to Participant:
These questions are centered on trying to get a feel for what it would be like to use the haptic display for long periods of time. They are trying to find out how using the haptic display affects you as the user.

1. **How are you feeling?**
    a. After training exercise?
    b. After "increasing points" exercise?
    c. After "virtual points" exercise?
    d. After "recognizing objects" exercise?

2. **What do you think of using the haptic display?**
    a. After training exercise?
    b. After "increasing points" exercise?
    c. After "virtual points" exercise?
    d. After "recognizing objects" exercise?

3. **How well do you feel you are doing?**
    a. After training exercise?
    b. After "increasing points" exercise?
    c. After "virtual points" exercise?
    d. After "recognizing objects" exercise?

4. **How hard do you feel you have to focus?**
    a. After training exercise?
    b. After "increasing points" exercise?
    c. After "virtual points" exercise?
    d. After "recognizing objects" exercise?

APPENDIX D

HANDEDNESS SURVEY

Code #___________

The Assessment and Analysis of Handedness: The Edinburgh Inventory

Have you ever had any tendency to left-handedness? Yes No

Please indicate your preferences in the use of hands in the following activities by *putting + in the appropriate column*. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put* ++. If in any case you are really indifferent, *put + in both columns*.

Some of the activities require both hands. In these cases the part of the task, or object, for which had preference is wanted is indicated in parentheses.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		Right	Left
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Comb		
6	Toothbrush		
7	Knife (Without Fork)		
8	Spoon		
9	Hammer		
10	Screwdriver		
11	Tennis Racket		
12	Knife (With Fork)		
13	Baseball Bat (Upper Hand)		
14	Golf Club (Lower Hand)		
15	Broom (Upper Hand)		
16	Rake (Upper Hand)		
17	Striking a Match (Match)		

18	Opening a Box (Lid)		
19	Dealing Cards (Card Being Dealt)		
20	Threading Needle (Needle or Thread According to Which is Moved)		
40	Which Foot Do You Prefer To Kick With?		
41	Which Eye Do You Use When Using Only One?		

APPENDIX E

PROTOCOL SCRIPT

This is the script to be read by the presenter during the experiment. Any words in italics are gestures or actions to be done by the presenter.

1. Introduction (15 minutes)
    a. Thank you for offering to participate in this experiment. My name is Mark Bailey. I am a graduate student in the Department of Computer Science. If you see me reading from the script it is to help me keep the presentation the exact same for all participants.
        i. *Reading of safety screening*
    b. . This next document is a consent form. It describes what you will be doing in this experiment. And your rights and responsibilities. After you have read it, and I have answered any questions you might have, please sign the document if you wish to participate in the experiment
        i. *Administration of consent form*
    c. This Next test is to find out your dominant hand. This is to decide which hand you will control the camera with and which will be used to type keys.
        i. *Administration of handedness test*
    d. Thank you, that is the main portion of the paperwork.
2. Training (10 minutes)
    a. This first exercise is to get you familiar with the haptic device and train your brain on how to use it. The computer will be transmitting the same information to the screen as well as the haptic display. The only difference between the two is the haptic display will also be receiving the answers.
    b. The goal of this exercise is to try to find the box covering the dot. As you select the correct box the speed of the dot moving will increase. Enough correct answers and the dot will start being placed under a random square so that you must rely on the haptic display for the correct answer. After 4 correct answers with random placement the number of squares will be increased to 16.
    c. Do you have any questions?
    d. OK, this is what I am calling a haptic display. It will be inside your mouth. For it to fit properly it should rest on your center of your tongue comfortably. There are electrical contacts that come in contact with your

tongue. The sensation that has been reported from previous experiments is similar to "pop rocks" on the tongue or sometimes tingling. It should not cause any pain. If it does please remove it from your mouth. If at any time you feel any discomfort or fatigue feel free to remove the device from your mouth and the testing will be paused.

e. Each electrical contact could be considered a pixel on a TV screen. The tests being done are to find out how well the skin can receive this information.
f. Do you have any questions about the device or anything else?
   i. *Check insertion and fit of haptic device in participants mouth.*
   ii. *Administration of training exercise*
   iii. *Removal of haptic device.*
g. We now have a few quick questions to make sure everything is going okay and to check how you feel.
   i. *Administration of fatigue survey*
h. You can now relax and take a break while I get the next exercise set up.

3. Number of pixels test (40 minutes)
   a. Now that you are familiar with how the display works we want to test if adding extra pixels will be recognized when you are using the haptic display. We are trying find out if there is a maximum number of pixels that can be recognized.
   b. For this next exercise there will be a screen displaying letters of different sizes. Your job is to control the camera with your non- dominant hand to focus on the letter. As soon as the letter is recognized type it onto the keyboard with your dominant hand. I will be recording the pattern that you move the camera in. The size of the letters will also be changing in a random order as well as the number of electrical contacts that are activated. The reason for this to be in a random order is to make sure there is no bias.
   c. This curtain is to ensure that you will be able to view the letters with only the haptic display.
   d. Do you have any questions?
      i. *Insertion of haptic device.*
      ii. *Administration of "increasing points" exercise.*
      iii. *Removal of haptic device.*
      iv. *Disclosure of participants percentage correct for guessing letters*
   e. Thank you, you are doing great. Now we need to update the survey.
      i. *Administration of fatigue survey*
   f. Go ahead and take a break while I get the next experiment set up.
4. Virtual pixels test (35 minutes)
   a. This next exercise is very similar to the last one. We are now trying to find how well artificial points can be recognized. When contacts are flashed quickly enough it can be perceived as a point in between the contacts. Again the number of points will be random as will the letter size.

b. Do you have any questions?
   i. *Insertion of haptic device.*
   ii. *Administration of virtual pixel test.*
   iii. *Removal of haptic device.*
   iv. *Disclosure of participants percentage correct for guessing letters*
c. Okay that is all of the tests for recognizing letters so we need to update the survey.
   i. *Administration of fatigue survey.*
d. Take a break while I set up the final test.

5. Object recognition test (15 minutes)
   a. This next exercise is to try to recognize normal everyday objects. These objects are things that you could use every day so this exercise is to see if these items can be recognized when you do not know what you are looking for. We will be using the settings that you have done best with for both the number of electrical contacts and number of virtual pixels so the main thing to try for is just to recognize the objects.
   b. Do you have any questions?
      i. *Insertion of haptic device.*
      ii. *Administration of object recognition test.*
      iii. *Removal of haptic device.*
      iv. *Disclosure of participants percentage correct for guessing objects*
   c. Alright great, that is all the testing we just need to update some surveys
      i. *Administration of fatigue survey.*
6. Final Survey (5 minutes)
   a. Thank you for your help. The last thing for you to do is to fill out a final questionnaire.
      i. *Administration of ending survey.*
   b. Do you have any questions about the purposes or methods of this experiment?
   c. Here is your money for your help.
      i. *Give money*

END

APPENDIX F

POST EXPERIMENT QUESTIONNAIRE

Code #__________

This questionnaire is to find out how you felt about the experiment. Your experience is important as part of the research.

1. **Rate the difficulty for each of the exercises:**
   very difficult difficult neutral easy very easy

   a. Training exercise:
   b. "Increasing points" exercise:
   c. "Virtual points" exercise:
   d. "Recognizing objects" exercise:

2. **Rate how accurately you could perform each of the exercises:**
   very low low neutral high very high

   a. Training exercise:
   b. "Increasing points" exercise:
   c. "Virtual points" exercise:
   d. "Recognizing objects" exercise:

3. **Rate how comfortable each of the exercises was:**
   very low low neutral high very high

   a. Training exercise:
   b. "Increasing points" exercise:
   c. "Virtual points" exercise:
   d. "Recognizing objects" exercise:

4. What was your general experience of the using the haptic display?
5. Do you have any aftertaste or numbness that might have developed more if you used this for extended periods or time?

6. Did you experience any problems during the experiment? How could it be improved?
7. Do you have any overall comments?

APPENDIX G

EXTRA INFORMATION GIVEN UPON REQUEST

Background

The haptic display is made up of a small grid of electrical contacts that is placed on the tongue. A cable runs from the tactile interface through a computer to a video camera that transmits its image to the tactile interface. After a while the brain recognizes the information being transmitted as spatial information and takes over. There is no longer a sensation of touch, in this case tingling, and it turns into a sensation of vision without affecting normal sight.

The reason that a haptic display works is there is some crossover between touch and vision in the human brain. The part of the brain responsible for vision, the visual cortex, is the part of the brain that is responsible for processing spatial information (Information on where things are located). What is just being found out is that it does not matter where this spatial information comes from, the brain will still process it. There has been research done that shows that a region in the brain that responds to both visual and tactile information (Amedi, 2002).

The skin does process some spatial information such as knowing where on the body skin is touched, or the sense of proprioception. So then comes in the question of how accurate it can be. Using the previous tests the tongue has been found to be have the highest resolution on the body (Boven & Johnson, 1994). Previous work (Weiss, 2001) has shown that the brain can understand information from a 12 by 12 grid. This experiment tries to find out if the points can be understood when closer together and when there are more of them. It does this by borrowing technology from the cochlear implant. A Cochlear implant is used to give people that are deaf the ability to hear. It works by turning electrical contacts on and off, or strobing, fast enough that the brain does not see a difference. So even though the brain does not sense it, there is only one electrical contact conducting electricity at a time.

This requires the knowledge of how the electrical contacts need to flash. The Meissner cells in the skin are used for feeling textures and receive information at about 40 hertz (40 times a second). So as long as all the electrical contacts in the display can flash in one fortieth of a second then the brain will see it as all contacts being active at the same time.

Another benefit of the use of strobing of the electrical contacts is the ability to convince the brain there are extra points in between the electrical contacts. If each electrical contact is flashed once then the brain thinks there is a point between the two points that was flashed. This allows for unlimited "virtual" points in a grid as long as the right pattern is used when flashing the electrical contacts.

This experiment will try to find if the attention ability of the brain is able to use the higher rate of information coming from the increased number of points and if recognition of "virtual points" is possible.

BIBLIOGRAPHY

Abrams, M. (2003). Can You See With Your Tongue? *DISCOVER*. Vol. 24, No. 06, June.

Amedi, A. (2002). Convergence of Visual and Tactile Shape Processing in the Human Lateral Occipital Complex. *Cerebral Cortex*. Vol. 12, No. 11, 1202-1212.

Bach-y-Rita, P. et. all (1998). Form Perception with a 49-point Electrotactile Stimulus Array on the Tongue: a Technical Note. *Journal of Rehabilitation Research & Development*. October 1, Vol. 35. 0748-7711.

Beauchamp,M.S. (2005).See me, hear me, touch me: multisensory integration in lateral occipital-temporal cortex. *Current Opinion in Neurobiology*. Vol. 15.145–53.

Blakeslee, S. (2004). New Tools to Help Patients Reclaim Damaged Senses. *The New York Times*. November 23.

Chorost, M. (2005). *Rebuilt: How Becoming Part Computer Made Me More Human*. Boston: Houghton Mifflin.

Ernst, M. (2002). Combining Sensory Information to Improve Visualization. *Proceedings of the conference on Visualization '02*. Session N2.pp 571-4

ITU (1992). Characteristics of TV receivers essential for frequency planning with PAL/SECAM/NTSC television systems, Recommendation BT.804 (03/92), March. http://www.itu.int/rec/R-REC-BT.804-0-199203-I/en

Goldstein, B.E. et. all. (2006). The cutaneous senses. *Sensation and Perception*, pp 437-45.

Gonzalez R., Woods R., (2002) *Digital Image Processing*, Prentice Hall. Second edition

Lederman S., Klatzky R. (2001). Designing haptic and multimodal interfaces: A cognitive scientist's perspective. *Proceedings of Collaborative Research Centre 453*. Technical University of Munich. pp 71-80.

Loomis, J., Lederman, S. J. (1986) Tactual perception. In Boff, K., Kaufman, L., & Thomas, J. (Eds.), *Handbook of Perception and Human Performance*, Volume II, Chapt. 31. New York: Wiley pp. 31-1 – 31-41.

Meijer P., (1992) "An Experimental System for Auditory Image Representations", *IEEE Trans. Biomed. Eng.*, 39: 112-121.

Nelson, M. (2006). Scientists aim for 'sight' through tongue. *Toronto Star*. April 24.

Newell, A. Gergor, P. (1997). Human Computer Interfaces for People with Disabilities. *Handbook of Human-Computer Interaction*. Second Edition, Ch. 35.pp 813-24

Novint (2007) Novint Falcon Overview. Retrieved June 3,2007, http://www.novint.com/falcon.htm

Oliver, R. G. Evans, S. P. (1986). Tongue Size, Oral Cavity Size and Speech. *The Angle Orthodontist:* Vol. 56, No. 3, pp. 234–243.

Ptito, M. et all.(2005). Cross-modal plasticity revealed by electrotactile stimulation of the tongue in the congenitally blind. *Brain*. 128(3). 606-614

Schmorrow, D., Kruse, A. (2004). Augmented Cognition. In W.S. Bainbridge (Ed.), *Berkshire Encyclopedia of Human-Computer Interaction*. pp 54-9.

SensAble Technologies (2007) Company: About Us. Retrieved May 5, 2007, http://www.sensable.com/company-about-us.htm

Van Boven, R.W. Johnson, K.O.(1994).The limit of tactile spatial resolution in humans: grating orientation discrimination at the lip, tongue, and finger. *Neurology*. Dec;44(12):2361-6.

Weiss, P. (2001). The Seeing Tongue. *Science News Online*. Vol. 160, No. 9, p. 140.

White, B.W. et. all (1970). Seeing with the skin. *Perception & Psychophysics*. Vol. 7(1). 23-7.

Zemlin, W.R.(1998). Articulation. *Speech and Hearing Science: Anatomy and Physiology*, Fourth Edition. 251-58.