Augmentative Communication Device
Hardware Development

BME 300
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Abstract

The goal of this project is to develop a novel method of communication for individuals suffering from a wide range of communicative disorders. Currently, there are no devices on the market that are fast, inexpensive, aesthetic, and allow the user to add emotion to their communication. We present work already accomplished, several design alternatives for hardware development, and a comparative weighted matrix to match our product design specifications. We chose to pursue a rechargeable compression driver based platform to be mounted on the head.

Background Information

Neuromotor dysfunction presents itself in a number of forms, one of the most common being cerebral palsy. This occurs in approximately 1 out of every 500 people and is a result of abnormalities in the growth and functioning of the brain[1]. This leads to uncontrollable reflex movements and moderate to severe muscle tightness. Cerebral palsy can be caused by head trauma after birth, but this is relatively rare. It is more common for the brain to be affected before or during birth.

Four main types of brain damage contribute to the majority of cerebral palsy cases[2]. The first is periventricular leukomalacia, which is damage to the white matter of the brain. This is usually responsible for transmitting signals throughout the brain and body, but small holes in this white matter that form before birth do not allow this to develop properly. Another cause of cerebral palsy is cerebral dysgenesis, or abnormal development of the brain. During the first 20 weeks of development, the fetal brain is very vulnerable. Any interruption in the growth of the brain causes abnormalities that interfere with the transmission of signals. Mutations in genes, infections, fevers, or trauma could contribute to this interruption. Intracranial hemorrhage, or bleeding in the brain, is also a possibility. If blood flow is blocked by blood clots in the placenta, the baby may suffer a stroke, leading to blocked or broken vessels in the brain. The final key development malfunction is hypoxic-ischemic encephalopathy, or intrapartum asphyxia. More commonly referred to simply as asphyxia, this is a lack of oxygen in the brain. Tissue in the brain, most notably in the cerebral motor cortex, can be destroyed, and this causes cerebral palsy.

Motor functions are affected differently in everyone; some have a slight limp, while others are completely wheelchair-bound. Those with spastic hemiplegia are mostly affected in the arms and hands; those with spastic diplegia are more affected in the legs and feet[3]. The most severe form is spastic quadriplegia, where one has severe stiffness in the limbs, is usually completely wheelchair-bound, and has extreme difficulties speaking. Cerebral palsy is a non-progressive disorder, meaning the disease will not worsen, but later physiological disabilities are very common.

Laryngeal cancer is not as common as cerebral palsy, only affecting about 1 in 22,666 people. This is a disease in which malignant cancer cells develop in the tissues of the larynx[4]. Sometimes called the “voice box”, the larynx houses the vocal cords and is found just below the pharynx in the neck. When a person attempts to speak, the vocal cords vibrate as air moves against them, producing sound. This sound echoes through the person’s mouth and nose to create a voice. The cancer typically develops in the squamous cells, which line the inside of the larynx. To treat the laryngeal cancer, many people choose to have a laryngectomy. In this procedure, the larynx is surgically removed. Since the vocal cords are located within the larynx, these are also removed. This causes the affected individual to lose all speech capabilities.

Finally, speech can be inhibited with a paralyzed diaphragm. The diaphragm is vital to normal respiration. In normal speech, air is required to be pushed up and out of the body. The diaphragm serves the purpose of pushing this air. When the diaphragm is paralyzed, the individual is not able to produce sufficient air flow to generate normal speech.

Problem Statement

As a continuing project this semester, our goal is to work from our "proof of premise" prototype to develop a smaller, more compact and convenient device that people with speech difficulties will find easy and intuitive to use. We hope to integrate the different hardware components into our own circuit and package it in an aesthetically pleasing way.

Design Requirements

One of the biggest complaints from patients with communicative disorders is that the devices out there to help them speak are slow and lack the ability to add emotion to what the user wants to express. This delay, between when the user thinks a phrase and when they are able to actually communicate, can make the user feel unintelligent or that they are being perceived as unintelligent. It can also leave them out of a conversation since they cannot produce language within the normal pause of a conversation. In addition, they are unable to add emphasis or inflection to what they want to say. These are the issues that our client, Dr.

Lawrence Kaplan, has asked us to address. Every day he encounters patients that are frustrated with the means of communication to which they are limited. Many of his patients give up trying to speak and let others do it for them. Our client is looking to break away from the conventional communicative devices that are on the market today. He would like us to come up with something new that allows the user to have more spontaneity when they speak, as well as the ability to demonstrate emotions such as irritation or excitement when they communicate. By doing this, we can hopefully “bridge the gap” for people with communicative disorders and help them to communicate in a way that feels more natural and comfortable.

The main feature that our client is looking for in the device is that it be phonetics-based instead of text-based. With sounds at their disposal instead of words, people have a wider variety of things they can say. They can put more personalization into their speech and incorporate slang. Working from this idea, we hope to make the device fast and intuitive so that the user feels that they are better able to express themselves, as well as feeling more apart of conversation.

Previous Work

This semester’s project is a continuation of work completed last semester. Last semester, we established the principal of the idea we are working from now. We used musical hardware in order to generate a “proof or premise” prototype in order to test the principal behind the idea. The hardware used included a Kaossilator as an input source and a talkbox as a mechanical sound source.

The premise of our idea is that sound can be funneled into the mouth and shaped by the mouth much like naturally produced sound is. By using the generated sound the user does not need to produce sound., which can be a problem for individuals with certain speaking difficulties The device replicates the function of the diaphragm and vocal chords by funneling sound into the mouth. This way, the user does not have to use their vocal chords or produce the air force necessary to work the vocal chords. One stipulation we knew would be necessary is that the user has control over their facial muscles so that they have the ability to shape the sound into understandable language.

The device works by taking an electronic input signal and converting it to mechanical sound. For our prototype the input came from the Kaossilator, using a setting that had a setting with vowel sounds. This input was converted by a compression driver in the talkbox to mechanical sound and funneled into the mouth by a vinyl tube. This sound is then shaped into language as the facial muscles modulate the frequencies generated by the talkbox.

Testing of the device showed that the understandability of the speech was best when the tube was placed about a centimeter in the mouth. This way the teeth could be used to occlude the sounds and create consonant sounds. It was found that the tube diameter did not affect the sound quality for the testing that we performed. We determined that a small tube would be best for the future design.

Inflection and emotion were also important factors in proving the principal of our idea. We tested the ability of others to understand whether the expression was a statement, exclamation or question, It was determined that the average rate of understandability was 91.11%, on the second iteration of the expression. This result can be seen in Figure 1.

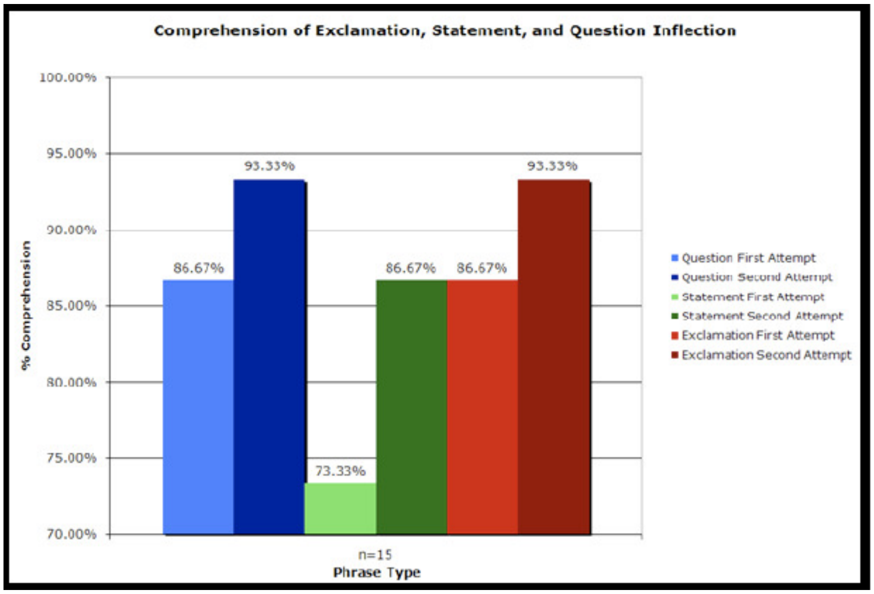

Figure 1. The inflection was understood 91.11% of the time on the second iteration of the expression.

The previous work on this project from last semester has laid the groundwork for the direction we will take this semester. We hope to integrate the hardware into a small, more compact device that is easy and comfortable for the user. Our previous work and testing has demonstrated that the principal behind the idea of this device is valid.

Design Alternatives

After evaluating our client requirements we proceeded to brainstorm potential designs to pursue. There were three aspects of the design we felt were important and required evaluation: the method of attachment, how to power the device, and the type of sound source to use.

Method of Attachment

There were several locations in which it would be feasible to carry around a device. We felt that there were a number of positions that needed to be evaluated including on the head as a cap, over the ear, around the neck, on the hip, integrated into a pair of glasses, and on the lapel. These locations were evaluated in a design matrix.

Power Supply

There are three options for powering the device. First, a rechargeable battery could be employed. Second, a set of standard disposable batteries could provide the required voltage. Finally, the device could be powered by whatever input platform is being used.

Sound Source

Finally, there is the source of sound to be used. Most professional sound is created by electromagnetic compression drivers, which provide the best sound quality. Other potential sound sources include miniature piezo-electric speakers, or small speakers found in standard computer speakers or boom boxes.

Design Matrices

Attachment

The design matrix was split into three different aspects, as they could all be independently evaluated. The attachment matrix is evaluated on four categories (Table 1). The first and most important criterion is the aesthetic nature of the device. In designing this device the needs of the end user must be kept foremost. The current market discriminates against users both visually and aurally. Devices both sound unnatural and look out of place. Allowing users to fit into society is a chief concern. The ear, cap and hip designs scored the best in this category, as they are the most easily integrated, or socially acceptable. The cap design can be covered by any standard hat or scarf while the hip design visually mimics a blood glucose monitor and the ear design mirrors a Bluetooth headset.

The second important criterion is the user convenience. For preliminary design there will be wiring connecting the hand control to the device, and tubing carrying sound to the user's mouth. Allowing the user to move freely is critical for user's who may already have motor limitations. The cap design only has one connection down the neck leaving it as the freest device. All other designs have more two connections coming from the user's head thus limiting head and arm movement. Ease of manufacture was also considered, as time is limited

Table 1. Attachment design matrix.

Factor	Weight	Neck	Ear	Cap	Hip	Glasses	Lapel
User Convenience	30%	4	2	7	5	2	6
Aesthetics	40%	3	8	9	8.5	1	4
Ease of Manufacture	20%	7	2	6	8	3	8
Cost	10%	8	4	6	8	3	8
TOTAL	10	4.6	4.6	**8.7**	7.3	1.9	5.8

to one semester for prototyping the device. Finally cost was given as a final category of evaluation. It was weighted lightly as all of these design alternatives will fall an order of magnitude below any device currently on the market.

Power Supply

The power supply is evaluated based on five criteria (Table 2). The most important factors were convenience and life cycle. Lithium Ion rechargeable batteries scored the highest in lifecycle, as they do not need to be replaced. Disposable batteries can provide the same amount of power as rechargeable Li/Ion batteries, however when they die they must be removed and replaced daily. Convenience was the second important criterion. It would be easy for the user if the device were powered by the input hardware however this would decrease the lifecycle of the device. Because it is assumed that the user will be recharging the input hardware daily, it would be easy for them to recharge the sound hardware at the same time. Size and safety were scored less critically as all possible designs were relatively equal. All

Table 2. Power supply design matrix.

Factor	Weight	Li/Ion	Disposable	Input Device
Size	20%	8	5	10
Safety	10%	7	7	9
Life Cycle	30%	8	2	4
Convenience	30%	8	4	8
Cost	10%	8	3	8
TOTAL	10	**7.9**	3.8	7.3

batteries have the potential to leak; however, if powered by the input device, there would only be one site of leakage thus explaining the slightly higher score in the Input Device category. For the life cycle, user convenience, and size, Li/Ion batteries were selected as the design to pursue.

Sound Source

The last aspect of the design to be evaluated was the sound source. Important factors addressed were size, frequency response, volume and cost (Table 3). Size was critical in creating a portable device that would be minimally visible and minimally invasive. The compression driver being evaluated had a largest dimension of 1”, so all designs scored well. Frequency response was the also critical. The compression driver provided the largest frequency band in the human range, while the speaker’s is slightly smaller and the piezo-electric speaker only has a single pitch. As all of these designs were inexpensive compared to existing devices cost was not an important deciding factor and could be used to justify testing multiple sound sources. Finally the output volume of the sound source is critical, as it would be beneficial for the user to be heard in social situations without requiring and external amplifier and microphone system.

Factor	Weight	Compression Driver	Piezo –Electric	Miniature Speaker
Size	30%	7	9	9
Freq. Response	30%	9	1	8
Cost	10%	9	9	9
Volume	30%	9	2	8
TOTAL	10	**8.4**	4.5	**8.4**

Table 3. Sound Source Design Matrix.

Final Design

Our final hardware design consists of two parts: an amplification system with a filter and a compression driver (Figure 2). First, we input the human sound into the filter. The filter used for our hardware would typically be a band pass filter with frequency ranges of 100Hz to about 3 kHz. This would remove the unnecessary noise that can creep into the system due to loose connections, thermal noise or interference from the sound source. Once the signal is cleaned, it needs to be amplified. The sound source is assumed to produce low amplitude signals. The source of amplification could result from either an audio filter with boosting capabilities or a normal speaker which would basically increase the amplitude of the signal.

Once we achieve the filtering and amplification of the signal, we need to pass this into a compression driver. A compression driver is a kind of amplifier working for high pressure systems. The entire signals that we produce need to be passed into a thin tube. This is achievable only with a compression driver. It is highly efficient and could also amplify the signal

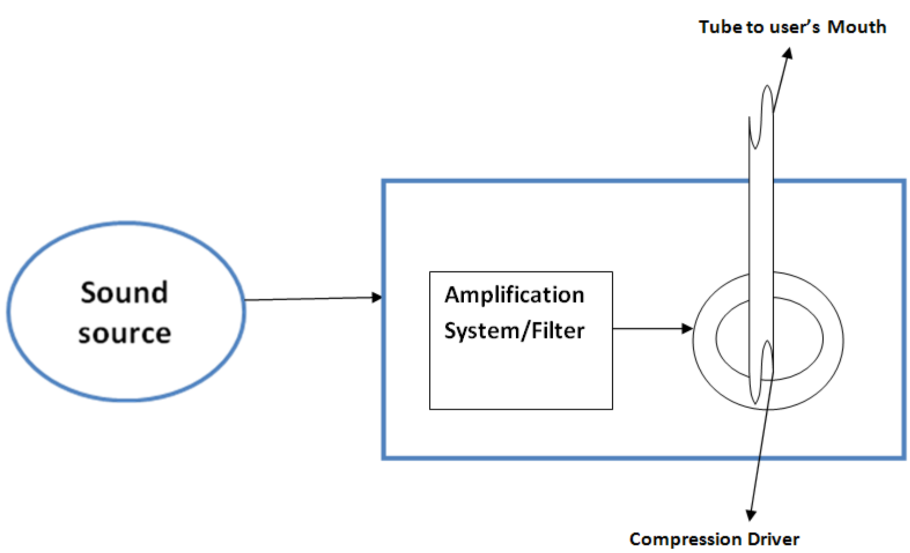

Figure 2. Our hardware comprised of the amplification system and compression driver.

by some amount. If during testing, it is observed that the signal is amplified by a large value in this stage we might not be required to use an amplifier at all. Different tube diameters need to be tested for obtaining a clear sound.

Future Work

We need to test for the right cut-off frequencies for designing the band pass filter. For this, we could either use LabVIEW or simply work with a breadboard and an oscilloscope. Stimulations also need to be tested for inputting sound into the filter and outputting sound into the tube. Thus, much testing needs to be conducted to obtain the right circuit for the amplification system.

Once the testing process is completed, we need to package our circuit into a PCB case. For this, we need to design the PCB with the help of tutorials present online. The PCB case would not only make the circuit compact but also make it commercially usable.

If we are capable of efficiently designing our hardware by the end of this semester, we would be required to work on the software part of it next semester. The sound source that is inputting sound into the hardware would be in the form of an iPhone application. This application would help the user play with the pitch and the tone of the prerecorded human sounds. This would thus help in adding emotions to the sound produced by the user.

Limitations

Since the user is required to lip sync in order to effectively use this device, damaged facial muscles and nerves that are involved in speech would inhibit the user from using our device.

The orbicularis oris muscle which surrounds the lip area is the main muscle involved in speech. Any damage to that muscle would prevent the user from using the device. Damage to other muscles like the buccinator and zygomaticus major could also limit one from effectively using this device. However, some words could still be produced in spite of damage to these two muscles.

Out of the 12 cranial nerves that are present in a human, the hypoglossal nerve is involved in articulation of speech and innervates the muscles associated with it. Hence, any damage to it could also prevent the user from using the device.

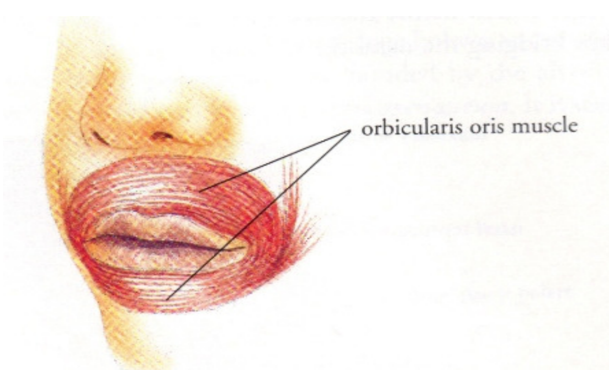

Figure 3. The orbicularis oris muscle[5].

Works Cited

[1]EMedicine. “Cerebral Palsy.” http://emedicine.medscape.com/article/1179555-overview

[2]National Institute of Neurological Disorders and Stroke. “Cerebral Palsy: Hope Through Resarch.” http://www.ninds.nihngov/disorders/cerebral_palsy/detail_cerebral_palsy.htm#88033104

[3]Gait Analysis Laboratory. “Cerebral Palsy Program/Guide.” http://gait.aidi.udel.edu/gaitlab/cpGuide.html

[4] National Cancer Institute. “Larnygeal Cancer Treatment.” http://www.nci.nih.gov/cancertopics/pdq/treatment/laryngeal/patient/

[5] Image: <http://72.233.24.94/~worldcf/wp-content/uploads/2008/12/f3.jpg>

Product Design Specifications

Function: To design a device that allows people with communicative disabilities but who maintain motor function to speak and express emotion with their voice. The device must provide immediate output, and it must be intuitive and accurate.

Client Requirements: The device should meet the following requirements:

Must be able to speak 30 words per minute

Must be understandable 75% of the time

Must be intuitive

Must be phonetics-based

Must not have any time delay

Must be adaptable to many forms of disabilities in terms of inputs

Design Requirements

1. Physical and Operational Characteristics

a. *Performance Requirements*: The device will be used daily and must be able to withstand a drop of 1m.

b. *Safety*: The device must not provide any risk hazards. It should not have any sharp, poisonous, or shocking parts.

c. *Accuracy and Reliability:* The device must enunciate, be audible and be able to produce functional statements

d. *Life in Service*: The device must be useable for three years

e. *Shelf Life*: the device must work after a 6 months of inactivity

f. *Operating Environment*: The device will be used in standard temperatures and pressures. It must withstand a small amount of water (equivalent to rain) and temperatures ranging from 0 – 37 C. It must resist the build up of body oils from daily use.

g. *Ergonomics*: the device must be adaptable to patients with a range of motor control

h. *Size*: the device should be easily transported, and be inconspicuous

i. *Weight*: the device should weigh less that 2 pounds

j. *Materials*: the device should be nontoxic and be able to be sterilized

k. *Aesthetics, Appearance, and Finish*: the device must be aesthetically pleasing and have a professional finish and appearance.

2. Production Characteristics

a. *Quantity*: for class purposes only one prototype

b. *Target Production Cost*: under $1000 (budget still undecided)

3. Miscellaneous

a. *Standards and Specifications*: There are no regulatory standards that this device must conform to.

b. *Customer*: The customer may have a wide range of physical disabilities which must be taken into account when designing adaptive interfaces and inputs for the device.

c. *Competition:* There are several devices on the market currently. They are all expensive, slow, cumbersome, and ineffective.