

Measuring Caloric Intake Using Chewing Sounds

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Abstract

Existing methods to track caloric intake provide inaccurate data due to their reliance on memory. Analysis of the chewing sounds that are conducted through the bones of the skull, specifically the mastoid process, will provide complementary information to monitor dietary intake. A microphone placed optimally, to achieve the highest resolution of only the chewing sounds, will provide information on food eaten. The three designs proposed analyze the positioning of the microphone as well as the method of amplification in order to optimize the quality of the recorded chewing sound.

Problem Statement

Over 1/3 of all Americans are obese; 2/3 are overweight [1]. In recent years, the incidence of weight-related disease, such as diabetes and cardiovascular disease has increased dramatically. Consequently, much effort has been channeled into finding ways to monitor dietary and exercise habits in the general population. Measuring caloric expenditure has been facilitated by invention of devices such as the pedometer.

However, measuring caloric intake has been a daunting task. Recording data on food intake has typically relied on the subject's memory and willingness to share. Scientific data obtained in this manner are skewed by inaccuracies. For example, in a society where excessive intake of unhealthy foods is considered to be a fault, a person may feel the compulsion to change his/her intake data to reflect him or herself in a more positive light.

In order to strengthen the value of the data, more accurate ways of measuring caloric intake are needed. Our team is exploring the possibility of recording and analyzing chewing sounds in an effort to facilitate a more accurate analysis. The recording will be performed by an effective microphone that is capable of recording different chewing sounds at differing frequencies. After recording, we will need a way of filtering the data so that it is distinguishable from other noises, such as speech. After the filtration, we should be able to relate certain intensities/frequencies of chewing sounds to the consumption of foods possessing different textures. In concert with other devices, we hope that the microphone will be a tool in monitoring dietary intake. It will aid as a tool for the memory and function as an accuracy check for survey data.

Background Information

Current and former research into analyzing caloric intake using chewing sounds has focused on correlations between among sound waves, food type, age, health, and sex. The research most pertinent to this project analyzed three types of foods: dry-crisp, wet-crisp, and soft texture. Furthermore, this same research, based in Switzerland, analyzed the microphone position in six locations: inside the ear, in front of the mouth, at the cheek, in front of the ear canal opening, on the collar, and behind the outer ear. Overall, the results of this study are promising, for the food types eaten correlated very closely to specific sound properties, particularly frequency. In about 60% of the tests, the scientists were able to determine the type of food, and certain foods, such as the dry and crispy type had even higher accuracies (up to 80%). Additionally, in almost 100% of the trials, the sound waves could be used to detect the start of a chewing sound (Amft *et al.* 2005).

Other pioneering research in this field comes from studying the acoustics of a normal swallow (cervical auscultation) and analyzing its properties. A research group in Australia analyzed the swallowing “signature” and correlated this to age, gender, and bolus volume. Their studies showed that both sexes and almost all ages have similar swallowing sounds when ingesting the same bolus volume (the amount swallowed). Furthermore, the group was able to show that the sound produced when swallowing was between zero and eight kHz, with length of swallow up to 0.8 seconds. The most relevant results of this study were that the most intense swallowing sound signal occurred almost exactly one second after the first signal detection of chewing without a great deal of variation in terms of age, gender, or bolus volume (Cichero and Murdoch 2002). Such results show that analyzing swallowing sounds may be a simpler task due to its small variations between individuals.

The equipment used in these studies included many high-end electronics and other lab equipment not easily available. One setup used in the Australian study involved two acoustic detector units consisting of an accelerometer and a Knowles microphone. This equipment allowed for maximal sound detection but had to be used in the controlled, soundproof lab environment. Contrarily, the study by Amft and colleagues studied only the positioning of one microphone and did not place the subject in soundproof rooms. Nonetheless, the microphones used in this study were particularly expensive in order to detect the quietest chewing sounds. With such expensive equipment, using chewing sounds to estimate caloric intake is restricted to the laboratory setting, which is very impractical.

Materials and Methods

Recording

Chewing sounds can be recorded inside the ear canal, and are transferred there very efficiently by bone conduction. These sounds are most easily captured with small gel probes designed to work with an audiological microphone. The gel probe is inserted into the ear canal, where it is exposed to the chewing sounds as well as partially shielded from ambient noise. The gel probe could possibly be adapted to work with other microphones, of a simpler and cheaper variety, in the interest of reducing cost. Regardless of which type of microphone is used, the signal is then passed to the amplifier pack.

The amplifier filters out the DC component of the signal, which contains no information related to the sounds recorded, making the signal easier to analyze. The pack also amplifies the signal, which is originally of a very low amplitude. Most audiology microphones include their own packs to which the microphones are easily connected. The pack is electrically shielded and

therefore not sensitive to ambient electrical noise. An alternative to this pack is the circuit design, which can be produced using common parts found in the lab, although measures must be taken to shield the device. After removing the DC component and amplifying the signal, the signal is sent from the amplifier pack to the oscilloscope.

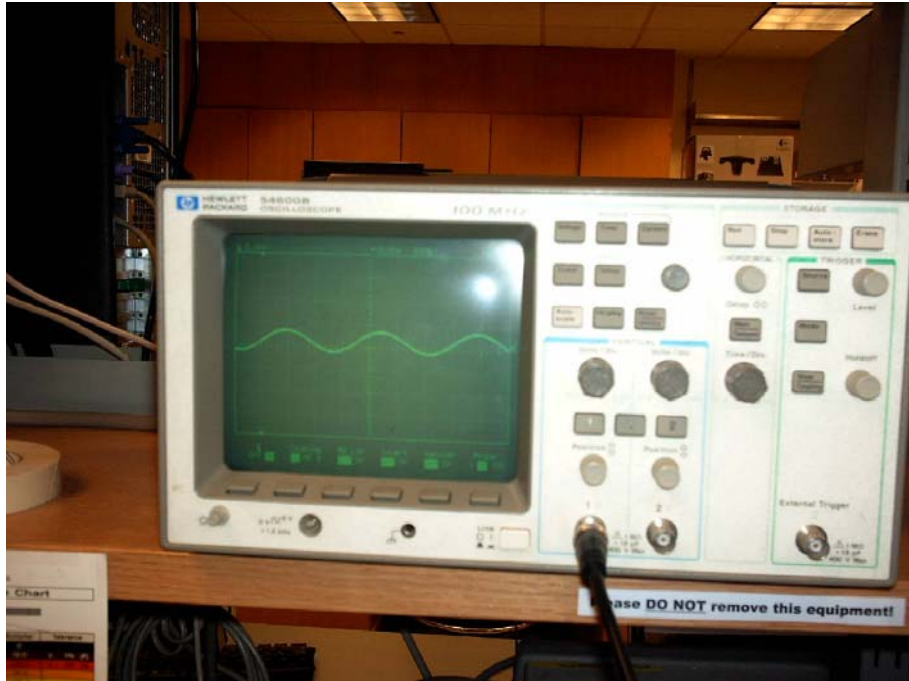


Figure 1. A student's whistling is recorded with the Audioscan microphone and displayed on the oscilloscope.

The signal that is transmitted to the oscilloscope is a time-varying voltage signal that contains information associated with the chewing sounds. The signal has two components, a frequency and an amplitude, both of which vary, depending on the type of food being consumed. Using the oscilloscope, the signal can be viewed and the values of the frequency and amplitude can be determined. When the oscilloscope is interfaced with a computer with Microsoft Excel, the signal is digitized and stored in an Excel spreadsheet as series of data points.

Processing and Analysis

Once chewing sounds are recorded, they must be analyzed to determine what type of useful data they contain. It is expected that foods with different compositions and textures will create different types of sounds when chewed. These sounds will vary in frequency and amplitude. The frequency of sounds produced can be analyzed using a Fourier Transform, which allows one to view the data in the frequency domain as opposed to the time domain. This allows for an analysis of the various frequencies present in the signal and their respective amplitudes. By viewing chewing sounds in the time and frequency domain, a great deal of information about the type of food that the subject is eating can be determined. By sampling a large variety of food types and textures and analyzing the chewing sounds that are produced, it may soon be possible to identify not only when chewing takes place, but also what type of food the subject is eating.

Ethical Considerations

There are several factors to take into consideration regarding the treatment of the users of this device. One important factor is user comfort. First, when a subject is sitting in a chair for a long duration to perform the tests necessary to record the chewing sounds, he or she needs to be provided with comfortable seating. The comfort of the microphone position is also important. If the microphone probe tube is placed inside the ear canal, it would need to be soft and not cause irritation in the ear. Additionally, care should be taken that the probe tube is not inserted too far into the ear canal such that it causes pain and discomfort or potentially puncture the ear drum. When inserting the probe tube into the ear, there is also the chance that it may lodge inside the ear canal. Consequently, attention should be paid to the length of the probe tube. It should be properly attached to the probe module that is attached to the outer ear. If the probe tube is too

short, it is placed all the way into the ear, and is not properly connected to the probe module, it could get stuck in the ear canal and be difficult to remove.

The second ethical factor to take into consideration with this project is hygiene. When using the microphone with a probe tube that is inserted into the ear, it is important to ensure that one probe tube is discarded after being used by a subject. If the same tube is utilized by more than one subject, there is the chance that bacteria from fluids will be transmitted from person to person. These bacteria can in turn, cause ear infections, contributing to pain and extreme discomfort.

In Ear Probe Microphone Design

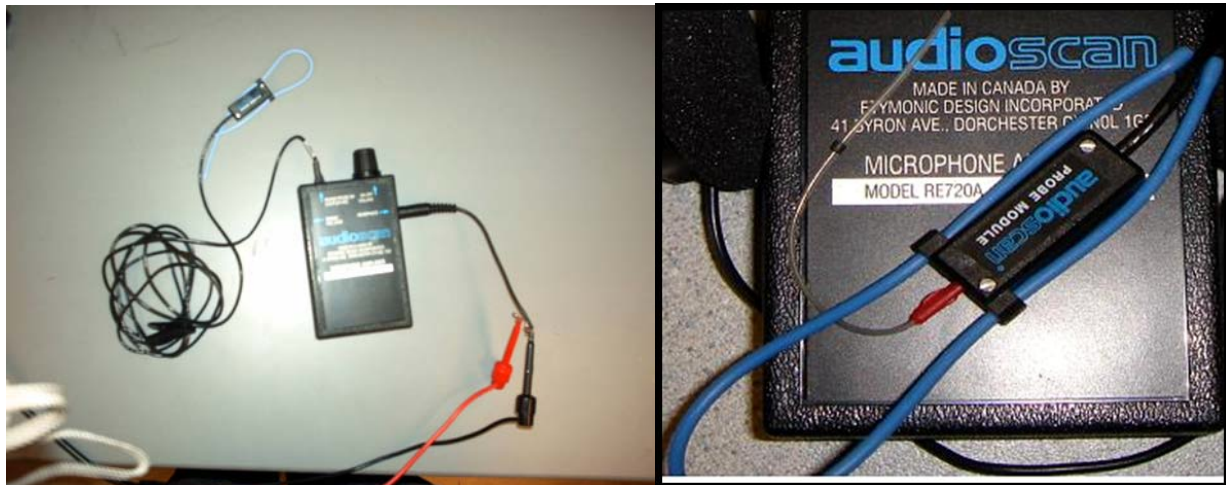


Figure 2. Left: The Audioscan microphone and amplifier pack. The output is attached to leads connected to the oscilloscope. Right: A closeup of the Audioscan microphone with a gel probe attached, resting on the amplifier pack.

The first design considered involves placing a probe from the Audioscan RE-720A microphone in the ear canal of the subject. This position allows sound from the subject chewing

to travel to the microphone by bone conduction of the skull and jaw, and thus, be recorded. The ear probes provided are composed of soft silicone and measure 76 mm long with a 1mm diameter. The probe module, which is the component of the system that holds the probes and contains the microphone, is secured to the outer ear with the included rubber strap.

The Audioscan microphone is powered by a 9-volt battery in the amplifier pack. This encased amplifier features a female 3.5 mm mini input for the probe module and a female 3.5 mm min output. A volume knob also on the amplifier controls the amplitude of the output. In order to capture the audio created by chewing, the amplifier must be interfaced with an oscilloscope. This was done by stripping a male 3.5 mm mini plug into two leads: an audio channel and a ground. A standard oscilloscope coaxial cable with two alligator clips was then connected from the channel input of the oscilloscope to the male plug output of the amplifier.

Through this setup the audio signals could be viewed on the oscilloscope screen, but for in-depth analysis, the audio waveform needed to be saved on a computer. The General Purpose Interface Bus (GPIB) connection between the oscilloscope and a Windows PC allowed for saving the waveforms as data tables and amplitude plots in the time domain.

Preliminary analysis of the waveforms obtained through this method show that chewing sounds recorded from the ear canal are clearly distinguishable from normal and loud speech. With the assistance of our advisor Dr. Webster, it was shown that chewing a hard pretzel produced a signal with higher frequency and amplitude components than the signals from speech. The clicking of the subject's teeth produced a signal with amplitudes higher than speech, but with amplitudes and frequencies still lower than with the pretzel chews. This demonstrated how sounds from hard and brittle foods like pretzels could be isolated. Softer foods with lower frequency sounds will be analyzed upon Human Subjects Research approval.

The Audioscan probe microphone system, which is primarily used for audiology and related research, provides a system with a low frequency response and a clean waveform. The ear canal position allows for an excellent isolation of chewing sounds because of its proximity to the mandible. Ambient noise is not recorded because the cylindrical probes capture the audio directly from the ear canal chamber.

This system, though very accurate, has some disadvantages. The probes were designed for safe use within the ear canal, but there is a slight risk of physical damage to the eardrum (e.g. scarring, puncturing) if handled improperly. The probes could also cause infection if reused by a different person. The main drawback of the Audioscan system is its cost. The Audioscan RE-720A is a discontinued model audiology microphone, and we received the system as a donation from the Audioscan. If a comparable microphone was to be purchased from the parent company of Audioscan, Etymotic Design Incorporated; the cost would be \$1500 (<http://www.etymotic.com/pro/er7c.aspx>). A way to replicate the results from the Audioscan microphone without having to utilize the expensive instrumentation will be explored. Possible alternatives include using a separate microphone with an adapter for an ear probe and using a separate circuit to amplify the signal from a less expensive microphone.

External Microphone Design

Our second design alternative is the idea of placing the Audioscan microphone on an external location. Several potential positions are the throat and the outer ear. To position the microphone near the throat, it could be attached to a piece of attire, for example, the collar of a shirt. To place the microphone near the outer ear, the probe module can be attached to the ear, and the probe tube, attached to the module, can be just hung outside the ear canal instead of

being inserted into the ear canal as in the first design. In this design, also, the entire microphone system will be attached to an oscilloscope which will record the chewing sounds and the data will be graphed in Excel.

There are several advantages to utilizing an external microphone for recording chewing sounds, including safety and comfort. Unlike the first design in which the microphone's probe tube has to be inserted into the ear canal, there is nothing that needs to be placed into the ear. Therefore, there is no cause of discomfort to the ear. There is also no danger of puncturing the ear drum with the probe tube. Secondly, this design is more hygienic than the first design. Nothing will be inserted into the ear that will be shared by subjects. With the in-ear microphone design, there is the chance that the tester will forget to replace the probe tube before the microphone is used by different subjects. The insertion of the same probe tube into the ears of multiple subjects can lead to transmission of ear fluids and other bacteria from one person to another and can lead to ear infections. Since the external microphone design does not have the requirement of placing anything into the ear, there is no danger of bacteria transmission.

However, the external microphone design does have its disadvantages. One disadvantage is that the microphone will pick up background noise and this will be recorded by the oscilloscope. This ambient noise will affect the readings produced by the chewing sounds and will not produce accurate results of the user's chewing. With an in-ear microphone, the background noise is filtered out, resulting in only the chewing sounds being recorded. There is greater accuracy with the first design.

Custom Amplifier Circuit Design

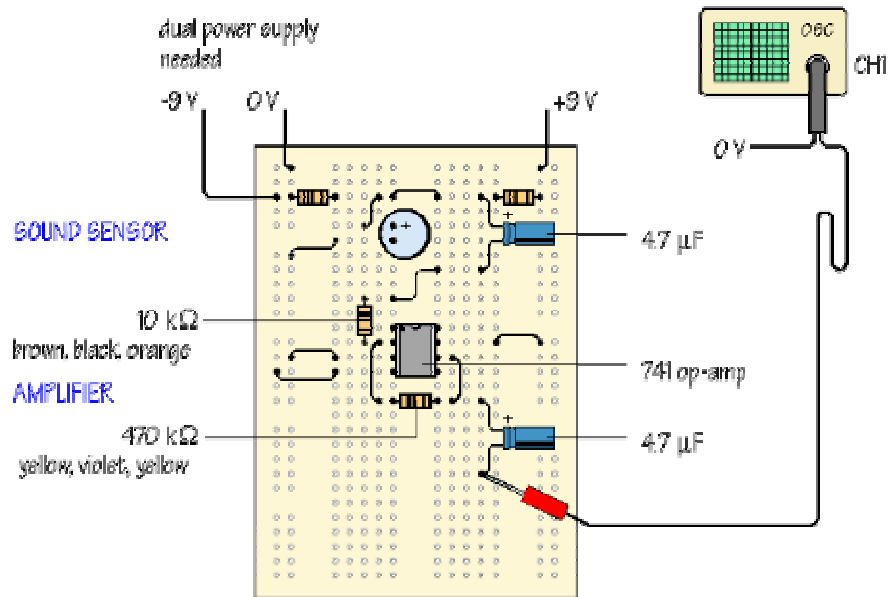


Figure 3. A diagram of the custom circuit used to deliver a microphone signal to the oscilloscope.

One method of recording chewing sounds involves using a microphone and a simple circuit. This circuit is a simple way to provide power to the microphone and convey the signal it produces to the oscilloscope. A crude version of this circuit can be built using a common breadboard, a 741 operational amplifier, and a small selection of resistors and capacitors.

The circuit provides power to the microphone using a +9V and -9V connection supplied by a dual power supply. A voltage division is used to deliver the proper voltage of two to three volts to the microphone. As pressure disruptions deform piezoelectric material in the microphone, voltage changes are produced in the signal corresponding to the pressure changes of the sound. The combination of capacitors and a 741 op-amp remove the DC component of the signal as well as amplify it so it can be viewed easily using an oscilloscope.

This circuit is a cheap and easy method of interfacing a microphone with an oscilloscope. Due to its simplicity, the circuit can be debugged easily and will work with any type of microphone. This would allow the use of microphones that are much cheaper and less specialized when compared with the AudioScan device. Modifying the probe system of the Audioscan device to work with a simpler, cheaper microphone may give comparable results at a greatly reduced cost.

The major downfall of this design is that the circuit is completely exposed to its environment and not carefully shielded like the Audioscan device. This makes it susceptible to electrical and magnetic noise that is common in most operating environments and is generally created by nearby electrical lines or devices. This can be especially difficult because the original non-amplified signal generated by the microphone is of very low amplitude. In order to achieve acceptable performance, the device would need to be properly shielded. The circuit portion of the device would need to be contained in a metal enclosing of some kind to create an environment free of outside electrical and magnetic fields and would be connected to the microphone and oscilloscope using shielded wires.

Design Matrix

Criteria	Weight	Inner Ear	Outer Ear	Throat
Isolation of chewing sounds	0.45	96	60	45
Sensitivity to background noise	0.25	97	55	30
Comfort	0.1	95	98	60
Safety	0.2	80	85	90
Totals	1	93	68	52

Criteria	Weight	Circuit	Audioscan
Quality of Signal			
Output	0.5	40	98
Sensitivity to Noise	0.3	40	97
Cost	0.1	90	50
Ease of Use	0.1	90	99
Totals	1	50	93

Figure 4. Design Matrices. Above: Microphone locations are analyzed. Below: A comparison of recording devices.

When considering the position of the microphone, we regarded a number of factors to help us evaluate the optimal placement among three choices: the inner ear, the outer ear or the throat. We weighed the isolation of the chewing sounds and reduced sensitivity to ambient noise heavily, since the quality of the chewing signals depended on these factors. However, the safety of the subject was also a major concern. Analysis of the signals obtained from the three positions revealed that the best isolation of signal was obtained when the microphone was placed nearest the bones of the mastoid process, in the ear canal. Since the microphone was enclosed in this position, the sensitivity to the ambient noise was effectively reduced relative to the external microphone positions. This position, however, received a low score in the safety area, since it involves insertion of the probe into the ear canal. In spite of this, the inner ear canal received the best evaluation and will therefore be our proposed design.

Discussion and Results

Our group has been quite successful in accomplishing goals set at the beginning of the semester. We obtained several microphones and tested their frequency responses using a simple circuit. These microphones, being relatively cheap, had smaller ranges of frequency responses. In addition, we discovered that the circuit that we constructed was extremely susceptible to background electrical noise because it was open. Our next step would have been to find a way to amplify the signal from the microphone in order to obtain sharper resolution on the oscilloscope or to find a way to close the circuit off to external noise.

However, an audiological microphone was donated to the group by the AudioScan Incorporated, so the step previously outlined was not necessary. We tested the frequency response of the AudioScan microphone and found it to be satisfactory in that it matched the range of frequencies for chewing sounds (we were only about to test as low as 50 Hz because of the limitation of our speaker system). The low frequency response of the microphone was difficult to test due to the poor frequency response below 50 Hz of available speakers. We were also able to connect the Audioscan microphone to an oscilloscope and obtain clear signals, as opposed to the microphones used before.

After obtaining the microphone, we tested various positions from which to sample chewing sounds: in the ear canal, behind the ear and on the throat. The external positions were found to be unsatisfactory for optimal isolation of sound because of increased distance from bone conduction and increased sensitivity to ambient noise. Therefore, we decided that our data acquisition would be from the inner ear canal, where the probe of the microphone was placed closest to regions of higher bone conduction.

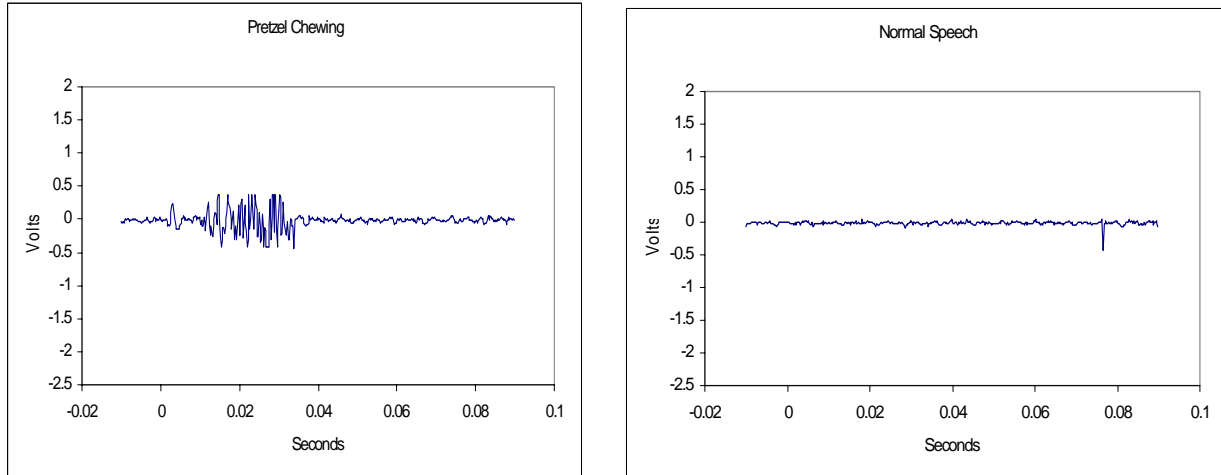


Figure 5. Visual representations of sounds recorded within the ear canal. On the left, a pretzel chewing sound is captured. Pretzel chewing creates a short burst of high amplitude, high frequency sound. It can be seen that the chewing sound can be differentiated from the in-ear sounds associated with normal speech, seen on the right.

Having decided on the method of acquisition, we started performing tests. We were not able to evaluate the system on ourselves because of concerns about human subjects testing with the Institution Review Board. However, Professor Webster was able to voluntarily test himself. We obtained three samples: one of Professor Webster's normal speech, one of his loud speech, and one of his chewing a pretzel. The signals of these processes were captured on the oscilloscope and then transferred to Excel as a function of voltage vs. time. The three inputs were analyzed, and it was found that the normal and loud speech signals were easily distinguishable from the chewing sounds. The normal and loud speech signals were rhythmic, and the amplitudes of the voltages from these signals were significantly smaller than the ones from the chewing sounds.

Future Work

Progress has been made on interfacing the microphones to an oscilloscope and to the computer. In the next phase of the project, audio signals from the chewing of varying softness

and hardness will be obtained. These signals will be analyzed and compared to determine if there is a correlation between the sound and the type of food, or even the amount of calories in the food. To assist in the analysis, the audio waveforms recorded in the time domain will be converted to the frequency domain by using a Fast Fourier Transform module in Microsoft Excel.

In order to avoid the cost of using an audiology probe microphone in future studies, alternative methods will be further explored. An example of this includes adapting a less expensive microphone that can accept the silicone ear probes, but still retain the frequency response and the sensitivity of the Audioscan microphone.

A shortcoming of the in-ear position, as mentioned, is the risk to the subject. Another possible option for the position of the microphone was suggested by Prof. Mitch Tyler. Placing a microphone on the mastoid process, the bone behind the earlobe, could offer a similar quality in chewing sounds without risk to the inner anatomy of the ear.

If successful with the capture and analysis of chewing sounds, work can begin on miniaturizing and enclosing the components of the system. The long-term goal of this project is to create a portable device that would be able to automatically capture and analyze the audio data in one unit. The work done this semester will serve as a precursor to this dietary monitoring device.

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Team 43: Chewing Sounds- Product Design Specification

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1. Background Information

Close to one-third of all Americans are obese. (<http://win.niddk.nih.gov/statistics/index.htm#whydodiffer>) Many researchers are developing ways to prevent this alarming number from growing. Monitoring caloric input and output are the main goals; analyzing habitual dietary and exercise data will help predict trends in obesity. Monitoring caloric output has been explored extensively. The pedometer, for instance, is a common tool that aids in measuring expended calories. Monitoring food intake has been a daunting task; many people rely on their memories to describe what they ate. To portray a better image of themselves, they may even lie about some of the foods they have eaten.

2. Function

In order to obtain more accurate data, our team is exploring the possibility of recording and analyzing chewing sounds. We will need to find an effective microphone that is capable of recording different chewing sounds at differing frequencies. After recording the data, we will need a way of filtering the data so that it is distinguishable from background noise (speech etc.). After the filtration, we should be able to relate certain intensities/frequencies of chewing sounds to the consumption of foods possessing different textures. In concert with other devices, we hope that the microphone will be a tool in monitoring dietary intake, paving the way for a healthy lifestyle.

3. Client Requirements

- Create a tool that accurately records what people eat, when they eat it, and where they eat it.
- To record the chewing sounds, either utilize a microphone that is placed inside the ear or some other location, such as near the mouth.
- The device should be able to distinguish between when a subject is chewing and when he/she is swallowing.
- The ability to record chewing sounds should be able to be performed numerous times.
- The chewing and swallowing sounds should also be able to be differentiated from other background noises.

If and when we have accomplished these requirements, Dr. Schoeller has some additional requests. They are:

- That the device is able to distinguish between what types of food are consumed, such as crunchy and soft foods.
- The device is able to identify the food and the number of calories that the subject consumes.

4. Physical and Operational Characteristics

- a. Performance Requirements:** The device used to detect chewing sounds will have use in the laboratory setting, but it has the potential to become a portable device after much initial testing. Using this device, we will record sounds and store this data until transmission to a computer source. Given the preliminary status of this experiment, the design will be used only in the laboratory and should experience minimal wear. The microphone will be placed into the ear by the user and will remain there for the period of testing, possibly as long as an hour.

Sounds produced by chewing can be detected by air- and bone-conduction. Frequency analysis of air-conducted sounds from chewed potato chips in the Amft study showed frequencies between zero and 10 kHz although the frequency range with highest amplitude for various crisp products are in the range of 1kHz–2 kHz. The soft tissue of mouth and jaw damp high frequencies and amplify at the resonance frequency of the mandible (160 Hz) when chewed with closed mouth (Amft, *et al.* 2005). The device should have a frequency response of approximately 20 Hz to 2 kHz.

- b. Safety:** In order to correlate foods to their sound patterns, we must test the device extensively using human subjects.

The risk of perforating the eardrum through the insertion of a microphone into the ear canal is minimal because the microphone will be placed far enough from the eardrum and still capture bone conduction. Furthermore, the construction of the device should be such that there is no risk of the microphone slipping farther into the ear canal and possibly puncturing the eardrum. One risk with the microphone, however, is the spread of infection by use of the same earpiece by numerous subjects. An infection could lead to puncture of the eardrum, but sanitary habits should prevent any possible exposure to these types of infections (All Refer Health).

Another issue to be considered is the possibility that the microphone becoming lodged in the canal. Problems that can result from this include pain and discomfort. Additionally, temporary hearing loss can occur since the ear canal and eardrum are occluded. The microphone would need to be removed immediately to restore hearing.

Contact transmission of infection through devices such as headphones, hearing aid and probes is a potential health concern. The risk of developing infection is great if the hearing device is not sterilized in between subjects. Not sterilizing the microphone between uses provides microbes an easy access into the ear orifice, establishing infections quickly, especially in people with a weaker immune response. Also, when bare hands are used in removing hearing tools, the risk of transmission is increased, as microbes are capable of entering the body through epithelial tissue. A safe way is needed to interface the subject and the microphone (Infection Control in Audiological Practice).

- c. **Accuracy & Reliability:** Previous studies (Amft, *et al.* 2005) have achieved 80-100% accuracy in food determination, and we hope to replicate and improve upon these results.
- d. **Life in Service:** Since this field has not received a great deal of attention, the device will have to perform for hours at a time in order to obtain enough analyzable data. The sound detector will have to perform for many hours in the laboratory and for many weeks (and months if this study continues).
- e. **Shelf Life:** Shelf life is not a concern in this stage of the project since our goal is to obtain, analyze and report data. This will become a concern once the design of a prototype has commenced.
- f. **Operating environment:** The device must operate effectively in a lab environment. This environment may include noise sources including external sounds and subject movement and speech that should not hinder the device from operating effectively.
 In the field, the device must operate effectively in a reasonable temperature, pressure, and humidity range that the subject could be exposed to in their everyday life. External noise or other influences such as speech, ambient sounds and subject movement should not hinder detection of chewing audio.
 Battery life at a minimum must last the length of an average waking day, or roughly 16 hours.
- g. **Ergonomics:** In the eventual development of a prototype, the microphone and recorder should not impede with the normal daily activities of the wearer.
- h. **Size and Weight:** The device must be of portable size, shape, and weight. Carrying the device throughout the day should not place undue burden on the subject.

 The average ear canal is 26 mm long with a 7mm diameter, and as such, the microphone must have approximately a 7 mm diameter. If a microphone tube is used, it must not extend more than 20 mm. (U.S. Department of Labor Occupational Safety & Health Administration)
- i. **Materials:** The three components of our analysis are: the microphone, recorder and an analyzer (computer).
- j. **Aesthetics, Appearance, and Finish:** Ideally, the device would be small and relatively unnoticeable to both the subject and others so it could be carried inconspicuously throughout the day.

5. Production Characteristics

The goal of this project is to record and analyze data more so than to develop and market a prototype. This preliminary work is necessary so that in the future, a prototype may be developed.

6. Miscellaneous

- a. No information found about national/international standards and specifications.
- b. As this project involves human subject testing, we will need to get approval from the IRB (Institutional Review Board Services), even though we will only be testing amongst our own team. One of our clients, Dr. Schoeller, has offered to obtain this approval.
- c. As the microphone will be placed in the ear canal, it may need to be sterilized after testing each subject.
- d. Monitoring dietary intake is a novel idea. Although studies of chewing data have been published, a product with the client's specifications has not been marketed. No competition is anticipated.

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