Insula - Biophysical Music

Santa Clara University

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SANTA CLARA UNIVERSITY
Department of Electrical, Computer, and Bio-Engineering

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ENTITLED

INSULA - BIOPHYSICAL MUSIC

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Insula - Biophysical Music

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SENIOR DESIGN PROJECT REPORT

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Abstract

Insula is the first device to create music from multiple biofeedback sensors. Our system aggregates biodata from EEG, EMG, ECG, and breath rate technology into live audio output. Insula paints a meaningful and holistic picture of bioinformation, enabling users to control and direct their physiologies into art.

Keywords: biodevice, generative music, wearable technology, biosensors, MIDI synthesizer

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Introduction

1.1 Background

Context:

The past few years have marked a steep rise in the presence of wearable technology. Biofeedback sensors such as electroencephalograms (EEG), electromyographs (EMG), and electrocardiograms (ECG) can all be found in commercially available and open source devices. These technologies have tremendous potential for peering into the body's state in real-time. There are non-clinical uses for commercially available biofeedback devices, including entertainment, gaming, market research, and meditation, but many of these possibilities are yet to be fully explored.

Problem:

Many of these commercial devices, including FitBit, Muse, Mindwave, aim to give users meaningful real-time biological feedback. Unfortunately, it is difficult for users to determine the accuracy and validity of this feedback. These devices appeal to the mass-market, so understandably, the raw data generated with these products is hidden and there is little functional information detailing the technical inner-workings of the products. The feedback generated by these devices is primarily visual; no devices take advantage of the emotive qualities of sound. Lastly, despite the accessibility of many different types of biofeedback sensors, there are no commercially available EEG products that integrate additional types of biosensors. Thus, existing systems only paint a partial picture of what the human body can tell us.

Solution:

Our product, Insula, will be one of the first devices to create music from information synchronously generated by multiple types of biofeedback sensors. Our multi-disciplinary team will design a system using EEG, EMG, and ECG technology to process biodata and output sound in real time. By correlating data produced across multiple sensors, we aim to present a meaningful and holistic picture of the body and mind and enable users to control and direct audible feedback. By allowing users to interact with the inner world of the body through sound, Insula will enable people to see, understand, and alter the biological data produced by their bodies in a creative and exploratory way. We envision a feedback loop between the user and the output which induces an intense feeling of entrainment, the synchronization of one's body to what appears to be an external rhythm, but is in reality created by that body's own heart rate, breath rate, muscular contractions, and brain activity. We hope to explore the benefits this technology can offer in the context of meditation, musical therapy, and the creative arts.

1.2 Literature Review

The purpose of the following section is to contextualize Insula within the field of non-medical, brain-computer interfaces and other biofeedback applications. It should provide for a thorough overview of the work our project builds on and contrasts with. This section will consist of both a general overview of the capabilities of EEG for extracting meaningful information as an analysis of a few specific biofeedback applications which successfully offer benefit to the average user.

Open Source Communities Lead the Way

The current development of brain-computer interface applications is heavily reliant on the work of online communities within the open source domain. This includes projects like OpenBCI, OpenViBE, Xth Sense, and numerous others. Additionally, major consumer-facing brain computer interface devices such as the Neurosky, Muse, and Emotive enable developers to create novel software applications with complementary software development kits for accessing the raw data harnessed by these devices. As a result, much of the progress in the development of software applications for Brain Computer Interface applications does not take place in conventional research settings.

This is especially true in regard to BCI-applications focused on exploring the artistic potential of EEG technology. Much of the latter territory is explored by diverse communities of independent technologists, artists, and developers all across the world. A prime example of one of these communities is the Open Brain Computer Interface project, OpenBCI, which provides flexible hardware for acquiring EEG, ECG, and EMG signals in parallel. This technology, which has been ported to a variety of software development environments, has a proven ability to enable the collection of meaningful biodata, allowing users to process multiple types of biodata synchronously. However, this approach is in its nascent stages and has yet to be fully explored.

It is important to note that with OpenBCI and other commercial brain computer interface systems, it is fairly difficult for users to actively control the biofeedback directly. However, there are a methods for doing this which have been proven to be effective.

The Centre for Computer Music Research at the University of Plymouth

Joel Eaton, a music neurotechnology researcher at the Interdisciplinary Centre for Computer Music Research at the University of Plymouth, utilizes the method of extracting Steady State Visually Evoked Potentials (SSVEP) brain activity to determine which of a set of flashing lights varying in rate a user is looking at. This enables the user to trigger computer commands by focusing their vision on the different flashing boxes. These commands were used in an installation to enable users to choose between different musical phrases to be performed live by a string quartet. This technology was intended to have applications for people with limited motion, however, using other technologies to analyze eye movement could pose a more direct method for achieving the same result, without the complex EEG signal processing workflow detailed below. A downfall of Eaton's technology lies in the fact that it requires the lights to be continuously flashing over the course of the session which could be unpleasant for users during extended sessions.

Classification via Pattern Recognition

There is an extensive body of research focused on the approach of 'training' BCI applications to identify electrical activity associated with different thought processes. A common manifestation of this approach is to detect motor imagery within the brain. BCI's can, in a sense, 'learn' and eventually recognize the frequency patterns triggered by moving a limb or by simply imagining it. This approach has been broadly applied to many gen-

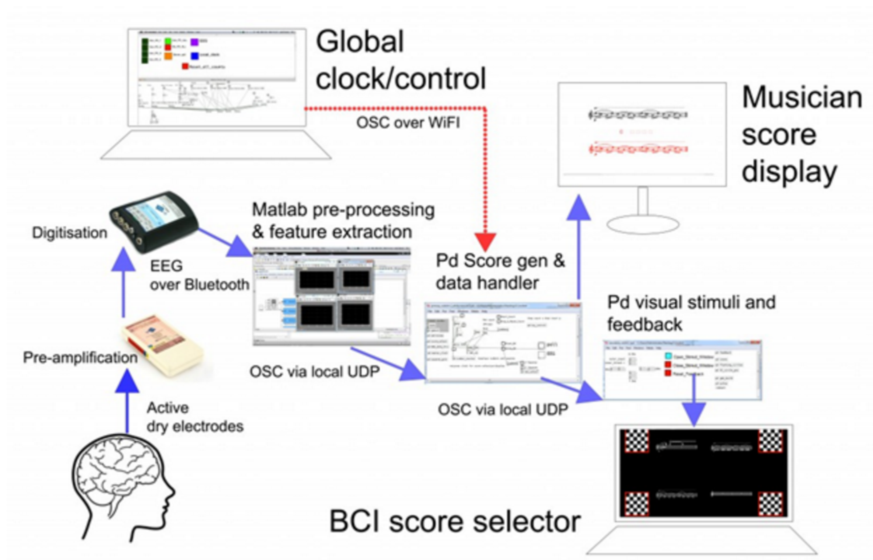

Figure 1.1: SSVEP Control Flow Diagram via http://joeleaton.co.uk/

eral thought processes. For example, with the Emotive system and software compatible with many devices such as OpenViBE, users can effectively train the BCI to identify brain activity associated with the imagination of different spatial movements so that the user may control the movement of a mouse. This training process can be particularly arduous and time consuming in order to work effectively. Additionally, it is difficult to distinguish between the recognizable, distinct frequency patterns from unwanted artifacts.

In contrast the complex process associated these learning algorithms, the extraction of Alpha wave activity offers the simplest way for the harnessing of user intention through EEG technology. Alpha waves are electrical frequencies in the 8-13 Hz range that are associated with wakeful relaxation and often increase in volume when a user closes their eyes. More on EEG frequency analysis is covered in the EEG section of this thesis, and in the appendix. Processing this frequency range to determine the intensity of these waves is core to the functionality of the majority of current brain computer interface systems, especially those which are purposed for meditation or mindfulness, such as the Muse.

BioMuse - Music Theory and EEG

Atau Tanaka is a prominent figure in the biophysical music space (4). Having a background both in the arts and engineering, he takes a more macro level approach to creating bio-digital music than other researchers in the EEG space. The core of his research comes from the contrast between the definitions of creating a tool vs creating an artistic instruments. While a tool is built with the need to solve a problem, or making a problem easier, an instrument is used to extend the capabilities of the user. It draws on ability to create with intention. With this in mind, his own invention, the BioMuse, is clearly distinct from other products. With the BioMuse, Atau is able to combine EEG biodata with the theory of creating music specifically in improvisation, gesture types, and generative feedback loops. Because much of the work in biosignal processing, especially EEG analysis, is very new to science (within the past 20 years), the community has often been closed and reduced to the esoteric group of scientific researchers. While this group has done great work for humanity, Atau shows us that the poetic and emotive approach brings a new dimension to the way we think about the physiological problems that are left to solve.

Xth Sense - Biophysical Music

Marco Donnarumma created Xth Sense (1), a biophysical music company. His research, originally conducted as part of the electronic music department at the University of London, consisted of studying the use of muscle activation for musical applications. Xth sense is a technology that extends some intrinsic sonic capabilities of the human body through a computer system that senses the physical energy released by muscle tissue. More specifically, it draws from MMG, mechanomyography, to detect acoustic signals created by muscle contractions from muscular vibrations and blood flow. These sounds are amplified, processed, and directed into a form of artistically unstructured sound. The uniqueness of Xth sense comes from the new way it acquires data. While most sensors in phones or wearable technology use accelerometers for locomotive data, MMG is able to directly represent the energy impulse that causes movement, rather than the consequence of that energy impulse. This low latency and high degree of controllability makes Xth sense valuable both as an artistic and accurate biofeedback tool.

Marco has written and published extensively about his research. One of his most prominent publications, Muscular Interactions, outlines MMG and EMG, their differences, and their methods of harvesting muscle activation data. The article talks about specifics in signal acquisition, processing, conversion to sound, and common difficulties in these processes. Finally, the article ends by exploring and validating different models to covert muscle contraction to sound by the user.

The article's conclusions highlight that both EMG and MMG are efficient methods to create visceral sound, but EMG tends to be more invasive to the user. The drawback with MMG however, is that it is difficult to get quality data since the sensor is acoustic based and can pick up unwanted noise. A gestural map of various muscle contraction types is highlighted to show what different movements sound like when converted to sound. These pieces of information will be critical to the development of our own muscle activation sensor. We have evaluated from this article that MMG is our ideal mode, and we will work to improve the signal quality. Compared to other research articles, this one is best for helping with troubleshooting and highlighting difficulties in the process of product development which we can prepare for.

While there is much to glean from the MMG work, there are a few major differences between Xth sense and Insula. Xth Sense was built to be primarily a performance instrument. Meanwhile, Insula's purpose is to help users gain a deeper and more holistic understanding of the connectedness of various physiological components and the role they can play to help users live a more healthy and creative lifestyle. The approach that Xth Sense takes in combining biology with art is novel and offers much to learn in this new space. Perhaps of most value from Xth Sense is the philosophy that there is creative potential in biology that is yet to be tapped.

1.3 Project Objectives

The goal of this project is to create a device which uses a combination of multiple passive biosensors to produce biophysical music, that is, music generated by the collection and manipulation of biological signal data.

Insula is a wearable device that translates bioelectricity into audio feedback, with the goal of making this information available, digestible, and ultimately useful to a broad market. Insula will simultaneously monitor multiple systems of the body, including the brain, the muscular system, and the heart. Data from these systems will be collected via electrodes, filtered, and processed. In the processor, bioelectrical information will be processed, and music will be algorithmically created and played back to the user.

The biosignal data has the following control flow to transform from raw electrical activity into audio output, explained in the System Requirements section.

Chapter 2

System Level Overview

2.1 System Level Requirements

This section serves to outline the objectives and specifications for our system. Functional requirements specify the capabilities of the system while non-functional requirements specify the manner in which the capabilities will be achieved.

The following section will consist of the requirements for the physical components of our system, with a more detailed description of the requirements for the software application component of the system in the software section of this paper.

Functional Requirements

1. The system will harvest biosignals in real time using biosensors, includ-

ing ECG, EMG, EEG, and a breath rate sensor.

2. The system will convert the analog signals into digital information to be made accessible by a desktop application.

3. The system will parse the incoming data and register physiological events, such as a heartbeat, the onset of specific EEG activity, muscle activity, an inhale, or an exhale.

4. The system will map these physiological events to musical events.

Non-Functional Requirements

1. The system will be lightweight, non-intrusive, and easy to use.

2. The system will be comfortable and aesthetically pleasing.

2.2 System Overview

1. USER: The user wears a “suite” of bio-sensors which will pick up electrical activity and physiological events:

    - Electrocardiogram -ECG (measures heart activity)
    - Electectomyogram - EMG (measures muscle activity)
    - Breath Rate Sensor
    - Electroencephalogram - EEG (measures brain activity)

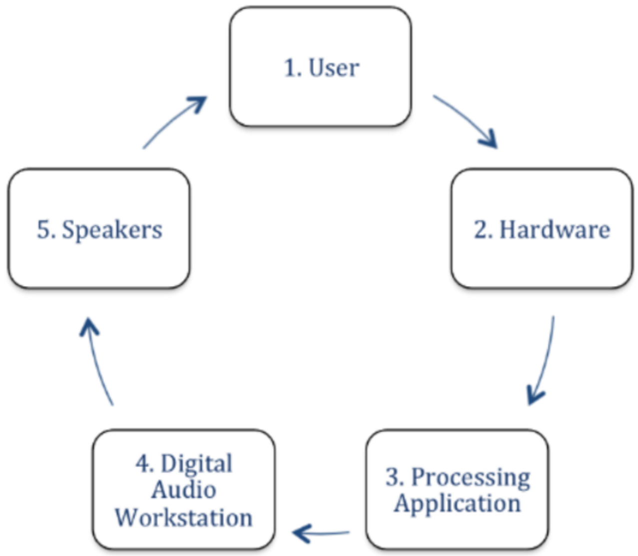

Figure 2.1: Stages of Dataflow through System

2. HARDWARE: The voltages measured by the sensors are digitized into discrete values by the hardware.

    - OpenBCI 8-input Board: Passes digitized voltage values to the software application
    - Arduino: Performs low-level signal processing and sends messages to software application

3. PROCESSING APPLICATION: Implements necessary feature detection algorithms and synthesizes music in the form of MIDI; written in Processing. MIDI messages are sent to a Digital Audio Workstation

4. DIGITAL AUDIO WORKSTATION: MIDI messages are received by

software instruments in music software such as Logic, Ableton, or Pro Tools where it is converted into audio.

5. SPEAKERS: The user hears their physiology in real-time, and uses this new awareness of the body to direct and control the feedback their body is creating as desired.

2.3 Functional Analysis

Given the system level requirements, Insula can be separated into the following key subsystems:

1. Biosensors
    - Electroencephalogram
    - Electrocardiogram
    - Electromyogram
    - Breath Sensor
2. Feature Detection Algorithms
3. Software Application

The electroencephalogram (EEG) collects electrical activity of the brain. We have used two electrodes on the cerebral cortex, and have additional pins available on the circuit board for the occipital lobe. Data undergoes a Fast

Fourier Transform (FFT) to convert from the time to frequency domain for analysis. Frequencies of interest are filtered in the software application.

The electrocardiogram (ECG) collects electrical activity of the heart. A typical waveform is known as the PQRST complex. Individual beats are detected via custom algorithms and sent to the software application.

The electromyogram (EMG) collects electrical activity of muscles. We chose to place the electrodes on the brachioradialis muscle, the largest muscle in the forearm, for maximum response and intentional control. The signal is smoothed and sent to the software algorithm.

The breath rate is collected via the change in resistance of a stretch resistor that stretches over the intercostal muscle of the abdomen. Boolean values of inhale (1) and exhale (0) are sent to the software application.

The software application is written in the Processing program language and operates on the user's computer (as opposed to the biosensor microcontrollers). The digitized physiological features of interest are correlated to musical parameters (such as pitch, volume, tempo etc.) and written to MIDI files, making the biosensor a MIDI controller. These MIDI files can be played by many standard music software applications.

The device consists of a suite of hardware and software working in real time and each subsystem is evident as you trace the packets of data throughout the device. The first stage of the process is signal acquisition, which is done through the four mentioned biosensors: EEG, ECG, EMG, and breath rate. Second, the data is passed through low level signal processing algorithms and feature detection algorithms to highlight the physiological events of interest. Third, the "cleaned up" data goes through the software application to generate MIDI files for music creation.

2.4 System Level Issues

One of the main challenges of designing our system was that each component of the system must be compatible with the rest of the sensors.

2.4.1 Compatibility

For example, when designing or choosing our sensors, we needed to make sure they are compatible with the pins on our hardware. When choosing our software, we needed to be sure the medium for our software application is capable of communicating with the hardware. This leads to a somewhat complex interdependence of design decisions, as changes with one component can ripple through the rest of the system. Often, a minor change to one component in the system caused changes in requirements for the others.

Additionally, while there is a lot of information available online about the individual components of our system, there was not much out there to serve as 'proofs of concept' for integrating them. Thus we were relying on educated assumptions about how the components of our system would interact. Many of these assumptions were proven false in testing.

One of example of this, which will be elaborated on in the technical hardware section of this paper, is how we needed to integrate Arduino in addition to our OpenBCI hardware in order to access the voltage divider functionality for our custom breath rate sensor.

2.4.2 Mitigation Strategy

In general, we did our best to make decisions that optimize flexibility and compatibility. We allocated responsibilities according to the interdisciplinary breakdown of our team. Thomas, the electrical engineer, was responsible for researching and configuring the hardware for our system, the bioengineers, Mohit and Samuel, were responsible for designing and/or configuring sensors, and the computer engineer, Chris was responsible for writing the software to build the application. Our development process required continuous interfacing between these fields and careful incremental testing with each new design decision.

2.5 Team and Project Management

2.5.1 Constraints and Challenges

Coordination and organization make or break the productivity of any team. This was especially difficult for our situation given that our team had full class schedules, extracurricular commitments and jobs at varying times throughout the week. Because of this, we began the school year meeting whenever we were all free, without any set schedule. We would have weeks where we met multiple times and weeks where we did not meet at all. During these meetings, we only sometimes had an agenda of what we wanted to accomplish. This often led to inspiring but not necessarily productive meetings. We would often conclude meetings without laying out goals to accomplish before the next meeting. This led to us each researching what interested us and often times a few of us would end up researching the same subject. This worked fine but it certainly was not the most efficient way to spend our time.

In terms of organizing our communication, we originally did most of our discussing over text or email. This worked early on when we only had one or two more general projects going on at once and everyone was involved in each project on some level. It quickly became intractable, however, we started having four or five projects progressing in parallel. Two people working on the same project would communicate in their own, separate email or text thread which made it so other people were unable to reference their discussion later. This lead to the same discussion happening multiple times over multiple threads.

Towards the end of Fall quarter, we essentially cut out email as a means of team communication and made the move to using Slack, a group messaging system, in addition to Groupme, which came to be used solely for miscellaneous group communications (mostly for planning meeting logistics). Slack was immensely useful because it allowed us to organize our discussions into threads based on different projects or subsystems. This allowed each of us to contribute to discussions that were relevant to us and to still retain the ability to reference the discussion of other projects that we were not as deeply involved in. A screenshot of our current Slack threads is below with our threads shown on the left hand side of the screen.

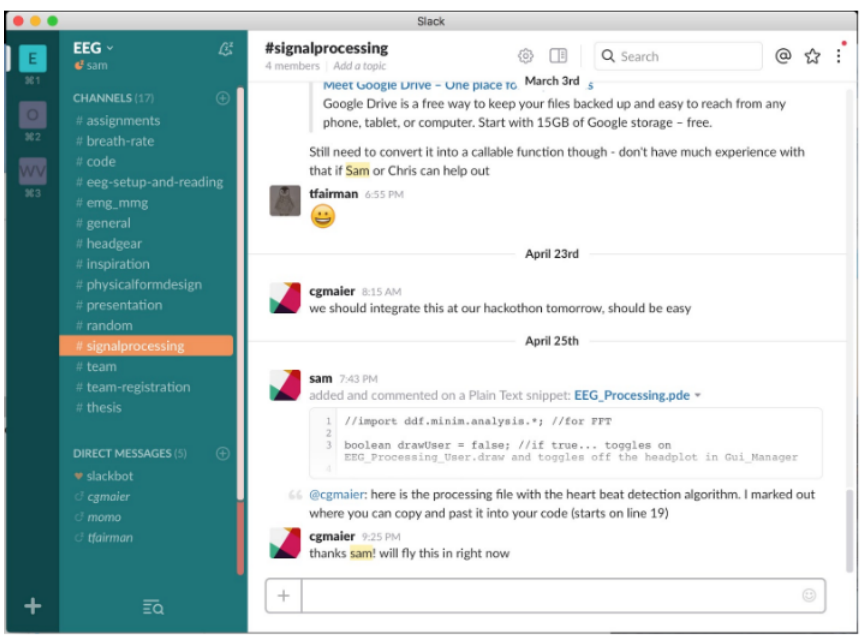

Figure 2.2: Stages of Dataflow through System

Slack also allowed us to create more in-depth posts in a blog-like format. With these posts we could create more in-depth documents for summarizing research or thoughts while incorporating figures and even sections of code. Additionally, everything within Slack is searchable which made referencing all of our discussions and decisions in Slack a breeze.

Around the same time we moved to Slack we decided to use Google drive as our primary document hub. This allowed us to keep all of our work organized but also prevented us from having multiple create the same content more than once, presentations especially. We were therefore able to keep track of what documents and figures each person had created and to see the progressive changes to each draft of each document or presentation. Lastly, Google Drive integrated directly with Slack. This allowed us to quickly share changes to documents quickly through Slack, all while keeping the links up-to-date through Google's web-based document editor.

In addition to streamlining our communications, we also created more structure around our meetings to further boost productivity. Towards the end of Winter quarter, we implemented regular bi-weekly meetings from 8:00 to 9:00pm on days when we all agreed we would be free then. We also prioritized goals to complete before the next meeting and assigned specific deliverables to each person. This greatly accelerated the pace at which we were able to identify and solve problems.

With Slack and Google Drive, we were able to keep all of our work and discussions available and search-able to every group member. This increased our productivity and reduced the chance of any of us doing work that someone else already had. Adding more structure to our meetings and individual work further enhanced our productivity and enable us to complete more than we all expected.

2.5.2 Budget

We received $1,115 from the School of Engineering, which turned out to be sufficient for the original plan we laid out for our project despite the few changes we made along the way. A summary of our spending is below.

Item	Cost
OpenBCI Board + electrodes (wet)	$539.89
medical tape, electrode paste	$51.44
MyoWare EMG board	$37.99
EEG Gold Cup Electrodes	$75.59
OpenBCI Case	$14.98
Breath Rate sensor materials	$5.00
Arduino Nano Boards (2X)	$19.98
Wiring for all electrodes	$5.00
Case for full system	$9.99
Headband for Headset	$6.53

Figure 2.3: Budget

As shown above, the OpenBCI board was by far the largest expense we incurred. In retrospect, we believe we should have purchased at least a few of these boards as it would have made our development with it much faster. Because we only had one board, we were forced to pass the board back and forth between each other and thus only one of us was able to spend time working with it at a time.

The next most expensive item we purchased were the gold cup electrodes for our EEG readings ($75), which was followed closely by the Brain-Computer Interface textbook we purchased. Without gold cup electrodes, we would have been unable to obtain reliable EEG data however we had to purchase a pack of about 10 when we only needed three electrodes. The textbook was extremely useful for getting us up to speed on EEG processing and the electrode placement we would need to achieve our goals.

2.5.3 Timeline

We had an initial jump start on the progression of our project. We formed our team towards the end of junior year and spent the summer doing some individual research. When we came back together in the fall we were ready to dive into developing our project concept. We did more structured research, had meetings and started collecting inspiration from other projects that we ran across. We reached out to and had informational dialogues with people heading projects that got us excited, like Xth Sense and OpenBCI. We even built our first sensor: a mechanomyogram (MMG), which we later decided not to use.

We became so enraptured in researching the current product space around our project that our research stage continued well into winter quarter. About midway through winter quarter we received our OpenBCI board and began familiarizing ourselves with its hardware and the Processing software that integrated with it. We experimented with various software tools for processing and creating audio feedback, ultimately settling on using Processing as the core of our application. We also began looking at the other biosignals and sensors that we could incorporate into our project.

Towards the end of winter quarter and the beginning of spring quarter, we realized that we had spend a little too much time researching and doing high level design thinking with not enough time spent actually developing the technical aspects of our technology. With the design conference only a few months away, we shifted gears from high level concept development to actually implementing all the ideas we had spent the last two quarters refining. We started having at least two meetings each week with whole day hackathons on the weekends. Because of this, we made an incredible amount of progress in our spring quarter. During this time we developed our breath detection, EMG, Arduino and wireless subsystems. This was the time in which we took our project from a head of disjointed ideas to a fully integrated prototype.

2.5.4 Risks and Mitigations

The primary risk we had for our team came from that fact that we had members of multiple disciplines working on many different subsystems. This meant that each of us had subsystems that we understood very well and others that we only grasped at a high level. With this arrangement we risked not being able to move forward if one our members was not around to fix or explain a certain subsystem. To mitigate this risk, we made sure to take the time to understand how each sub system worked as it was added on even if we were not directly responsible for it. Later on in the project we began having formal ‘workshops’ that ranged from quick demonstrations to full meetings where the experts on certain subsystems would teach the other members how a certain subsystem worked and/or how to use and troubleshoot it. We had these workshops on how to use our Github account, Processing code as well as how to setup and code the OpenBCI and Arduinos.

Chapter 3

Subsystems

3.1 Subsystem Overview

Insula can be broken into two broad subsystems: hardware and software. Hardware consists of the biosensors and electrodes, as well as some low level signal processing and feature detection algorithms on two separate microcontrollers, the OpenBCI board and the Arduino board. The software application operates on a computer and works as a MIDI controller to convert the processed biosignals into MIDI files for music generation.

3.2 Subsystem Components

1. OpenBCI
    - Electroencephalograph

    - Electrocardiogram
2. Arduino
    - Electromyograph
    - Breath Rate
    - Radio Frequency Module
3. Software Application

3.3 Hardware

The hardware subsystem of Insula consists of biosensors and microcontrollers, and serves the purpose of acquiring analog electrical and mechanical signals from the body and then relaying those signals to computer software as digital information. The functional requirements follow. The hardware system of Insula must:

1. Detect bioelectrical activity on the heart, the muscles, and the surface of the brain via electrodes on the skin

2. Detect breath-rate via a stretchable resistor around the torso

3. Translate analog biological activity (as distinct from electromechanical noise) into digital information

4. Send digital information to computer software to be translated into MIDI

First, our device must interface with a body - what does that mean? Essentially, it means our device must function as an intermediate layer between a human and software. Our device's interface is where it is physically picking up signals from a user. The two examples of interface in our project are the electrodes and the stretch resistor. These media are physically changed by the user (electrically stimulated in the case of electrodes, mechanically stretched in the case of the resistor).

Second, these analog changes must be received and translated into digital information for transmission to a computer. The data must be indicative of human activity and not of random noise present in the environment. Since the device exists in a universe in which billions of electrical systems are operating close to one another, noise is omnipresent - in the form of electromagnetic radiation from power lines, phones, and wall outlets, as well as electrical signals from unintentional human movement (unintentional movement is defined as movement in parts of the human body not connected to our system)

Third and last, the data received by our system must be sent to a computer for processing into music. This can be accomplished via wired or wireless means, but a processor must be able to pick up the data.

3.3.1 OpenBCI Board

The OpenBCI project board is the base for Insula. The OpenBCI is an open-source biosensing platform created by Joel Murphy and Conor Russomanno in 2013. The board has the capability to pick up EMG, ECG, and EEG data simultaneously while being compatible with standard clinical electrodes. This is critical, as it fills our functional requirements of using multiple biosensors in real time. The board itself, as shown in the figure below, has 8 input channels, local SD storage (as a data buffer), wireless RF communication, an accelerometer, and a high-frequency analog-to-digital converter. After data is collected on the OpenBCI board, it can be sent over bluetooth to a computer hosting the OpenBCI graphical user interface (GUI), written in Processing, for data analysis and visualization. This GUI is the basis for our MIDI synthesizer application.

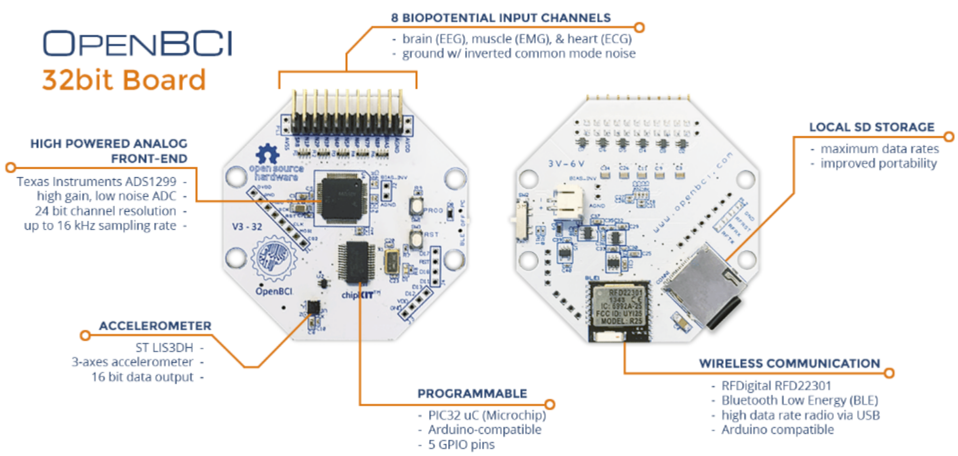

Figure 3.1: OpenBCI 32 Bit Board

The board has has adjustable gains, which allows it to differentiate and scale the intensities of different biosignals. This is critical for our use to be able to process between the vast difference in magnitudes of signals coming from EEG, which operates on the order of microvolts, compared to ECG and EMG, which operate on the order of millivolts. The ability of the board to processed information partially via hardware systems, frees up software computing power for music generation and other higher level signal processing.

Finally, we needed a board with a high sampling rate, which allows it to pick up the data being created by the brain at high frequencies. The brain is constantly sending neural impulses in dynamically changing frequencies, ranging from 2-20Hz (see appendix). High sampling rate allows us to relay a clear a picture of its movement as possible. The OpenBCI board offers 16kHz sampling frequency, whereas an Arduino or similar microcontroller is limited to 1kHz. For these key reasons, OpenBCI was the predominant design choice for data acquisition.

We utilized our OpenBCI board to acquire two of our biosignals: the electroencephalogram (EEG) and our electrocardiogram (ECG), because of the need for high sampling frequency. EMG and and breath rate is acquired via Arduino, as outlined in section 3.3.2. In this section we will discuss the process through which we settled on the placement of each electrode as well as on the basic hardware filtering that is done on the OpenBCI board. The methods for which we identified features in each biosignal are discussed in Section 3.4.

Electroencephalography (EEG)

We originally conceptualized EEG as being the core of our project. Because of this, we had planned to have multiple electrodes around the scalp such that we would be able to accurately categorized the user's mental state. However, for reasons described in our conclusion, we ultimately decided to let our other biosignals take center stage while the EEG would play a smaller role.

Regardless of how many electrodes we decided on utilizing, it became eminently clear that we would need to stick to, or at least roughly follow, the internationally accepted 10-20 system for our electrode placement. The reason for this is that all of the research focused on correlating EEG signals to mental or emotional states is based on this system. It provides a standard arrangement, with corresponding labels, by which researchers can compare and reproduce their findings. The international 10-20 system is shown below.

Our primary goal with EEG was to capture Alpha waves, which exist between 8 and 13 Hz. The are most prominent in your occipital lobe, positions O1 and O2 above, when your eyes are closed; this is because your occipital lobe is responsible for your visual processing. To accomplish this, we purchased EEG electrodes with 'combs' or spikes on them that are designed to penetrate hair in order to secure a reliable electrical connection to the skull. Securing these electrodes to the occipital lobe in a reliable and ergonomic way proved itself to be beyond the scope of our project so we ultimately decided to place a single, gold cup electrode on position Fp1, on the forehead. This position still allows us to detect Alpha wave activity while providing us

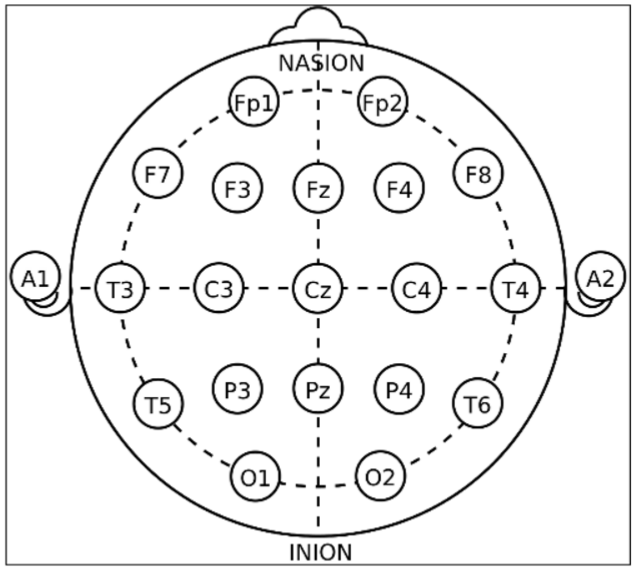

Figure 3.2: International 10-20 EEG Placement System

with a much easier location on which to place the electrode. We also placed another gold cup electrode at position A1 to act as a ground, which is fairly standard among the research papers we read.

Once we have the electrodes placed on the user's head, the leads are connected to the OpenBCI board. The electrode at Fp1 is connected to one of the standard input pins while the electrode at A1, our ground, is fed into common ground pin of the OpenBCI. This allows us to use common mode rejection to cancel out any extraneous noise, primarily from the heart beat. The signal is then run through a 60Hz notch filter to remove the AC circuit noise and a 1 to 50Hz bandpass filter. Lastly, the signal is then amplified 24-fold before it is passed off the computer for feature detection.

Electrocardiography (ECG)

The electrode placement for our ECG signal went through several iterations over the course of our project. Obtaining a clean, reliable ECG signal while the user moved around the room posed a greater challenge than we originally anticipated. Ultimately, our iteration strategy for our electrode placement strove to minimize the number of muscle groups between the electrodes in order to minimize the potential of noise in the signal. Each iteration and it's pro's and con's are summarized in the table below.

Iteration	Electrode Placement	Pro's	Con's
1	One electrode on the middle of the inferior side of each forearm.	Ease of placement	Any arm movement by the user resulted in an unreadable signal
2	First electrode just inferior to the left pectoral muscle, on the rib cage. Second electrode placed directly on the spine in the corresponding lateral position.	Much less prone to noise than the first iteration	Difficult to place back electrode by yourself. Susceptible to significant noise when the user moved side-to-side, likely due to the erector spinae muscles.
3	Both electrodes directly inferior to the nipple, on the rib cage	Almost no noise from the user moving about. Relative ease of placement.	Large T-wave on the ECG due to electrode placement makes simple threshold peak detection infeasible (see figure below).

Figure 3.3: Heart-Rate Algorithm Development

Unlike our EEG, we chose to utilize disposable electrodes for our ECG

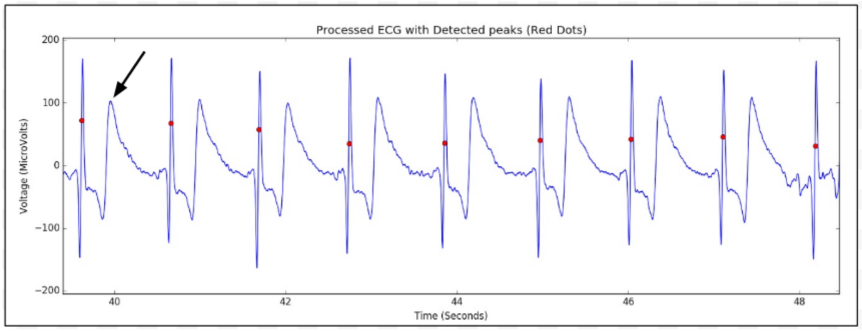

Figure 3.4: Processed ECG with detected peaks (indicated as red dots). The first T-wave is indicated with the arrow

electrodes. We chose to do this primarily due to ease of use as the disposable electrodes do not require any extra preparation (i.e. adding gel and/or taping). In the long term, we hope to move to dry, reusable electrodes that are integrated into a band or shirt in order to maximize ease of use as well as minimize long term cost.

The two leads from the ECG electrodes are fed into two input pins on the OpenBCI that, once set-up through the software, are run through a differential amplifier which serves to cancel out any common mode noise. This set up also allows the EEG to maintain a separate reference electrode from ECG, which is necessary due to the fact that EEG and ECG signals are orders of magnitude different in magnitude, uV vs mV, respectively. Similar to EEG, our ECG is run through 60Hz notch and 1-50Hz bandpass hardware filters. It is then amplified 4 fold and then passed on to the computer for feature detection.

3.3.2 Arduino Board

As mentioned, the OpenBCI excels at performing high frequency data acquisition, which is ideal for the ECG and EEG waveforms. However, the high price tag of this device, $499.99, makes it unattractive from a user's perspective. For this reason we decided to offboard the EMG and breath rate sensor data acquisition to an Arduino Nano microcontroller, which can be bought for less than $10.00. Like the OpenBCI, the Arduino has analog to digital In/Out pins which can be used to input data. It has a programmable ATmega328 chip which the user can upload C++ code to do additional low level signal processing on. The sampling frequency of this board is 1kHz, which is suitable for the needs of EMG and breath data. With the addition of Arduino compatible RF modules, the Arduino board is an ideal candidate to work simultaneously with the OpenBCI board and GUI. The Arduino is also based off of open source hardware and software.

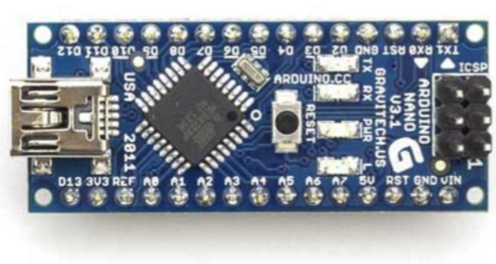

Figure 3.5: Arduino Nano

Electromyography (EMG)

The electromyogram (EMG) picks up electrical activity of the skeletal muscles. This electrical activity is generated from conduction of nerve impulses sent from the brain to muscle cells to cause contraction and relaxation. EMG is a key component when analyzing biomechanics of movement. With the goal of creating music that accurately reflects the physiological state of the body in real time, the Insula team decided that EMG would offer the user intentional control of the music he or she creates, which is unique compared to the other sensors which pick up signals from the autonomic, or unconscious nervous system. While EEG signals from the motor cortex of the brain could be correlated with the mental state associated with physical movement, the EMG provides a more useful method to track limb movement. In addition to intentional control, the kinetic nature of the EMG is a practical method to add dynamics and "movement" to the emotional underscore of the music.

These two design rationales lead the team to decide to integrate muscle activity data into the suite of bio-information which Insula would use. Benchmark analysis in biophysical music lead the team to find Xth Sense, a biophysical music company which uses mechanomyography (MMG) to translate movement into sound. MMG is distinct from EMG in that MMG picks up mechanical and acoustic vibrations of muscle and blood created during a muscle contraction. Initial research lead the Insula team to build a prototype version of the MMG, but results were mixed. The MMG picked up significant amounts of noise from shaking and unstable contact with the arm, and it was not immediately clear how to translate this acoustic signal into a pleasant sounding tone. Additional possible reasons for the lack of clarity in the signal could be because of increased noise in the signal as you travel down the pipeline of a muscle contraction, as seen in the figure below. Signals further down the signal get distributed through the tissue, rather than having a point source for observation. For these reasons, the Insula team quickly pivoted from MMG to EMG, which is known to have better signal clarity. The EMG collects electrical voltage from neurons causing a muscle contrac-

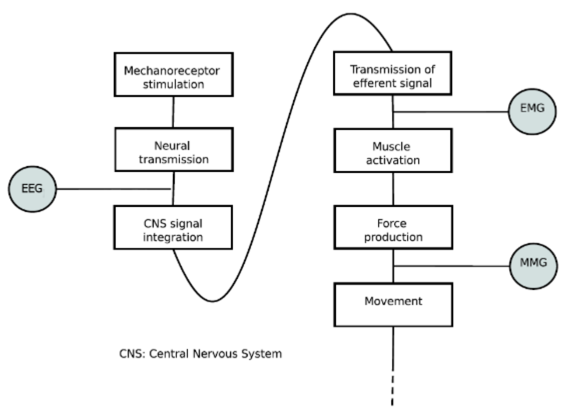

Figure 3.6: Sensorimotor System Information Flow

tion. For user friendliness, we chose to use skin surface electrodes, rather than electrodes which pierce the skin and get closer to the muscle, for Insula. The raw EMG signal from a contraction of a group of muscles, or motor unit, results in a stochastic burst of electrical activity, which when observed on a larger scale, is a rapidly oscillating peak centered on the resting potential, as seen in figure 3.7. This signal needs to be further processed by rectification, amplification, filtering, and smoothing before integration into the software application. Discussion and research the Insula team to decide to implement as much of this signal processing in hardware, rather than software, to save on cost and processing time.

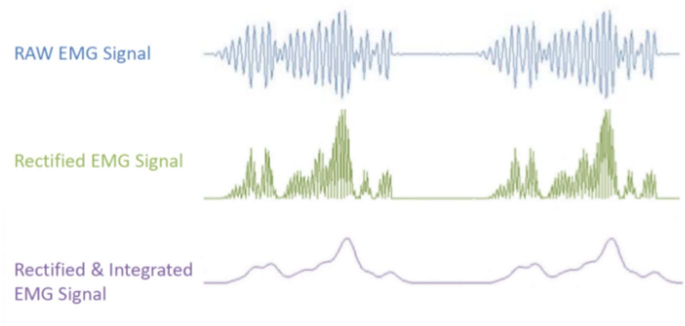

Figure 3.7: Raw EMG Signal and Processing fucntions

To address these signal processing needs, we chose to use the MyoWare 3-lead Muscle Sensor (AT-04-001). It can be seen on the next page. The MyoWare board is a low-cost EMG circuit board designed to output processed EMG signals to standard microcontrollers, including Arduino. The MyoWare uses differential amplifiers, diodes, and a potentiometer to offer rectification, common mode rejection, and amplification of the raw EMG signal. It uses two muscle electrode locations as well as a reference electrode for variable electrode placement. The combination of the built-in signal processing and microcontroller compatibility made the MyoWare a powerful design choice for the EMG.

In addition to signal processing, the other major component of acquiring a

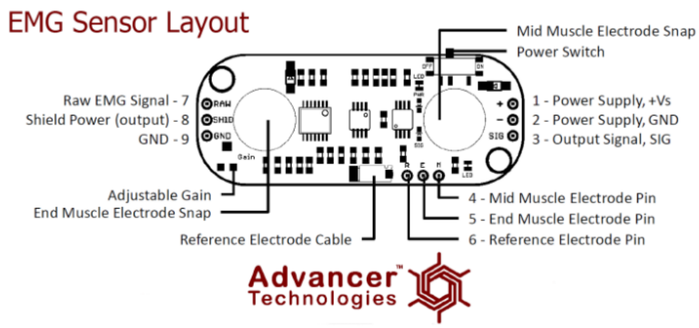

Figure 3.8: MyoWare 3-lead Muscle Sensor Layout

clean EMG signal is the focus on electrode placement. Due to the stochastic nature of a raw EMG signal, position and orientation is critical for clean, consistent, and strong biosignal conduction. Electrodes should be placed in the middle of a single muscle body, being sure not lay an electrode over two adjacent muscles. Additionally, the two differential electrodes should be aligned with the orientation of the muscle fiber. Adhering to these placement rules is necessary to maximize the strength and quality of the sensors signal due to maximizing the number of motor units measured and the avoidance of cross-talk between muscles. The mentioned placement can be seen in figure 3.9. For presentation and testing, we placed the electrodes on the brachioradialis muscle on the forearm. Future users can choose to place the electrodes in different locations, should they so desire.

This concludes the hardware construction, hardware signal processing, and electrode placement of the EMG. The next component of the EMG is the signal processing algorithms on software, which were achieved on the

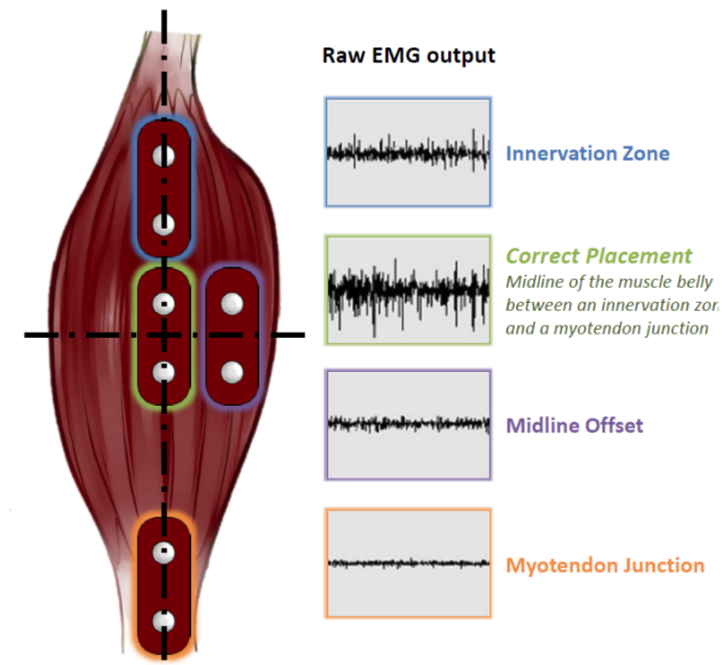

Figure 3.9: Electrode Placement and Raw EMG Outputs

Arduino microcontroller. The design rationale of completing the processing on the microcontroller, rather than the software application, is to reduce the amount of processing done on the computer, where MIDI file creation can be processing intensive.

Breath Rate Sensor

The fourth biosensor of the Insula system is the breath rate sensor. The respiratory rate is a strong indicator of subconscious physiological cues, such as stress, physical exertion and illness. In order to acquire dynamic and holistic real-time information about the body, the breath rate is an essential

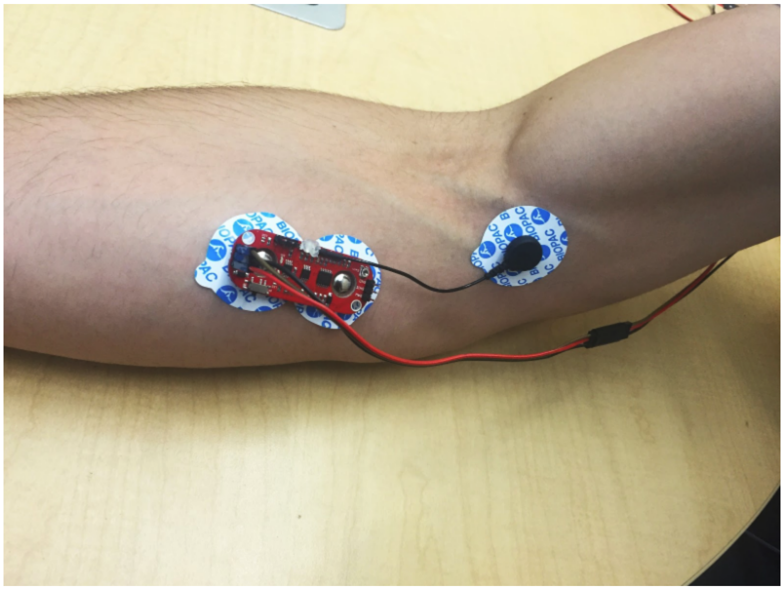

Figure 3.10: Electrode Placement for EMG on Brachioradialis muscle

biosignal. Clinically, the breath rate is typically acquired through changes in humidity, pressure or temperature from breath via a thermistor or similar circuit component. These sensors must be attached adjacent to the mouth or nose to pick up reliable data. This set up reduces the mobility of the user and interferes with user-friendly design. Some breath rate sensors take advantage of the intercostal muscle, which is responsible for the contraction and expansion of the abdomen during breathing. This physical change can be mapped to changes in electronic conductance for digital analysis.

In order to map these physical changes in volume to electric potential, we first looked at using a strain gauge to measure the change in deformation of the chest cavity. A strain gauge is a stress analysis tool which uses thin conductive foil to measure resistance. When the foil is deformed via pressure,

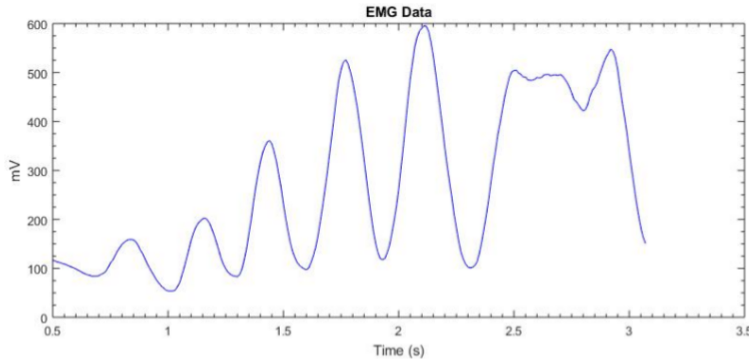

Figure 3.11: Processed EMG Signal with multiple thresholds and a sustained contraction

tension, or compression, its resistance changes. This change in resistance can be installed into a Wheatstone bridge circuit to accurately measure the change in resistance of the strain gauge, which ultimately correlates to the expansion of the chest cavity. However, strain gauges typically operate on the order of a surface of 2-10mm2 and measure strain deformations of 10%. Expansion of the chest cavity during respiration operates closer to several centimeters in strain, with deformations of 20-40%. Since this measurement exceeds that of the strain gauge capacity, in addition to an average cost of $50 per gauge, we opted out of the strain gauge.

However, using the volume and area changes of the chest cavity was still the optimal user friendly choice. Further research lead the Insula team to the hobbyist site, Adafruit.com, which sells a conductive rubber cord material, which can also be used a stretch sensor. The rubber cord is made from conductive material which lowers in resistance as it is stretched. The cord is 2mm in diameter and has a resistance of 140-160 ohms/centimeter, and would double in resistance when it reaches a strain of 100%. We were able to acquire the cord in one meter increments. We used this conductive rubber as a variable resistor in a voltage divider circuit, which allowed us to measure the change in electric potential across the cord when a current was running through it. This circuit works very similarly to the previously mentioned strain gauge, in that it converts a change in measured length to a change in resistance. The key difference is that the conductive cord can measure changes in strain on a broader level, but to less accuracy. This sacrifice is acceptable to compromise because Insula's goal is to report only the physiological event of an inhale and an exhale, and not more specific parameters such as lung capacity or breath volume.

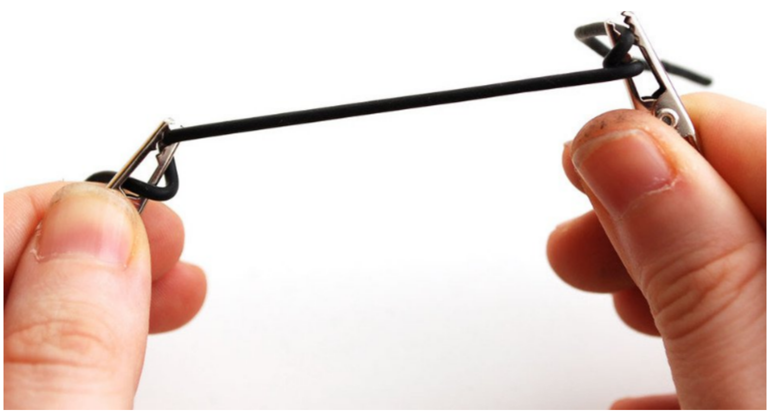

Figure 3.12: Adafruit's conductive rubber cord material

Once a raw signal is acquired, the next step is to filter the signal and implement feature detection to get a cleaner, more workable version, for the software. The first component of filtering is a RC hardware circuit implementation. A 2.2 uF capacitor in parallel with the variable conductive cord resistors holds in small charge potential across the resistor. Inevitable high frequency noise in the resistor, likely due to heat and other stochastic processes, is filtered out of the output signal. After hardware filtering, the potential across the variable conductive cord resistor is measured and read into the Arduino microcontroller.

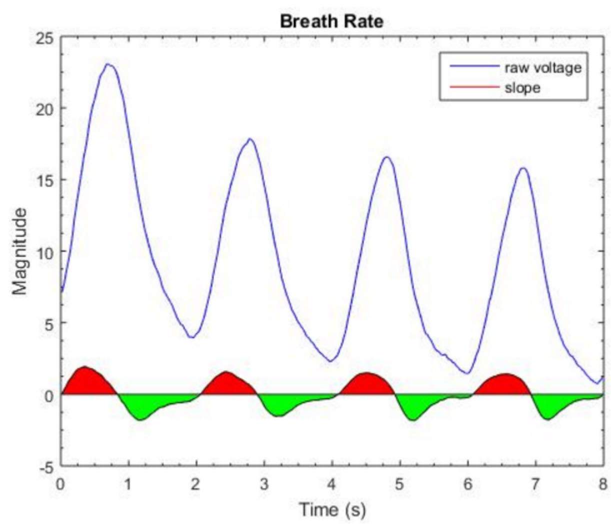

Figure 3.13: Breath Rate data output with Insula. The blue curve represents the breath rate, while the red and green curve is the instantaneous slope. Regions above the x-axis (area in red) correspond to an inhale, while areas below the x-axis (in green) correspond to an exhale.

Wireless Integration

Before we integrated wireless modules, our arduino's had to be physically connected to the computer via a USB cable in order to pass data along a serial port. This was undesirable because it meant the user was confined to a chair near the computer. It is also unsafe to be hardwired to a computer that may be connected to an AC charging source because our electrodes create a low impedance circuit with the user's body forming part of that circuit. By making the Arduinos wireless, we solve both of these issues.

To make our Arduinos wireless, we chose to use nRF24l01+ modules because they are extremely cheap (about $1 per radio) and they come with robust open source libraries that make integration with the Arduino very simple. They provide us with up to 50 feet of range and up to 1Mbps, which are more than sufficient for our needs. Because of the open source libraries, we can change all of the radio settings dynamically from the arduino. We are also able to hard code the channel selection and pairing process so that it happens automatically when the user powers up the system.

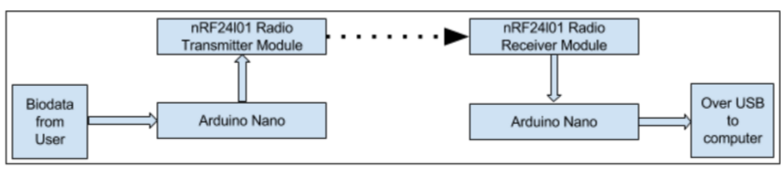

Figure 3.14: Flow Diagram of Sensor data from the user to the computer utilizing RF modules. Arduinos and radios communicate over an SPI bus

Our system utilizes two nodes arranged as shown above. The radios only communicate in one direction with the node by the user acting as the transmitter and the node by the computer acting only as a receiver. When the arduino on the transmitting side takes readings from each sensor it packages these values into a pre-defined data structure and sends all of the data points at once. Thus, the Arduino that is connected to the computer receives a single packet of data which it then parses out and sends to computer using serial communication.

After each packet, the receiving node sends an empty acknowledgement payload in return. The code is currently set up to allow for dynamic acknowledgment payloads which allows us to send commands from the computer to the arduino on the user without having to switch the radios from receiving to transmitting and vise versa, which requires them to be powered off and on. Although our current system does not utilize this, we foresee using this capability to dynamically initialize calibration procedures, change the gain on each sensor and/or to put the system into a sleep mode remotely.

Although these radios were relatively simple to set up due to the open source library, roughly 1 in 5 packets failed to send successfully when we first began using these radios. Further research revealed that, although the radios' average current draw of about 18mA is well within what the 40mA Arduino can supply, the radios exceed what the Arduino can supply during transmission bursts. This is especially true when we began setting the radios to their maximum power. To solve this, we soldered 10uF capacitors across the power terminals of the radios. The capacitors serve to supplement the current supply during a transmission burst.

3.4 Feature Detection Algorithms

3.4.1 EEG

Alpha is a brain state or neural oscillation, which is loosely correlated to wakeful relaxation. EEG signals that exhibit Alpha behavior are characterized by prominent peaks in the general range of 8-13 Hz. It is one of the few types of brain activity that shows up prominently in EEG signals and serves as the basis for a variety of consumer level products.

Fast Fourier Transform

EEG analysis requires the data to be translated from the time domain to the frequency domain. With the Open Source OpenBCI GUI code, we are able to perform a Fast Fourier Transform automatically on the incoming OpenBCI channels. The resulting FFT data is accessible through a two dimensional array, where the first index represents the OpenBCI pin and the second represents the frequency for which we want to know the voltage magnitude.

1st Iteration of the Algorithm: Averaging the Alpha range

Our original implementation of the Alpha detection range was to simple average the voltage values for the frequencies within the alpha range, and compare that average with a static threshold. This approach worked but was not robust enough the account for the user electrode placement and the raw variability in EEG signals.

2nd and Final Iteration: Peak Detection

The algorithm we ended up using to successfully detect Alpha activity from our EEG signals was found in researching and the OpenBCI blog of Chip Audette, an avid user of the OpenBCI hardware and pioneer of testing experiments with it. He conducted an informal experiment where he and some other OpenBCI hackers used their Alpha waves to control a remote control inflatable shark, and made all of the code used in his implementation publicly available and open source.

Instead of averaging over a set of bins, this algorithm looks for a distinct peak within the range of Alpha activity, and if a peak is detected that surpasses a static threshold, our system registers Alpha activity.

3.4.2 ECG

Detecting the individual heart beats from our ECG signal posed a much more complex problem than we initially anticipated it to be. The first iteration was a simple threshold algorithm. We determined a roughly arbitrary threshold voltage, above which the signal would trigger a 'beat' event. The primary problem with this design was that it failed to account for any of the possible variations between users and electrode placements. It would work fantastic on one user but not at all on the next. It also had no way of identifying and ignoring noise due to the user bumping an electrode or moving around.

Since the amplitude-based threshold approach was insufficient for the goal of our project, we decided to scrap it all together on our second iteration. Instead we decided to make an algorithm that looked for characteristics of the QRS complex's shape, specifically its slope. We noted that once our ECG signal was run through the hardware filters, any noise that we received had a very sharp uptake but a relatively slower return back to the baseline. Thus, the R wave of the ECG was the only part of the signal, including the noise, with a sharp uptake and a sharp downtake and we could therefore identify a heartbeat based upon the slope of its decreasing side. Using this idea, we set up a 'slope threshold' which would trigger a beat event when the signal's slope went below a certain threshold. The problem with this design came with determining what that slope threshold should be. If we made it too tight, the system would fail to identify any peaks on some users. If we made it too loose, then the system was highly susceptible to detecting false beats.

The last iteration of our heart beat detection algorithm came when we moved to our final electrode placement (one electrode inferior to each pectoral muscle). This electrode arrangement gave us a much cleaner and more stable ECG signal that is almost impervious to muscle noise and baseline shifts from the user's movement. Because we had a much more reliable signal, we came back to the idea of using an amplitude-based threshold but this time we decided to make it dynamic. As can be seen in the next figure, our algorithm is always keeping track of the peak and the trough (and thus the amplitude) of the last heart beat. Once a beat is detected, it then uses the difference between the peak and the trough to calculate the amplitude. It then sets the threshold at 80% of the last beat's amplitude and adds that value to the trough value to account for any baseline shifts. Beyond calculating a dynamic threshold, the system also keeps track of the last interbeat interval (IBI). It uses this to eliminate the potential of false triggers due to high frequency noise by waiting 3/5, which was an arbitrary choice, of the last IBI until it will look for the next beat. Our final beat detection algorithm is summarized below in Figure 3.15.

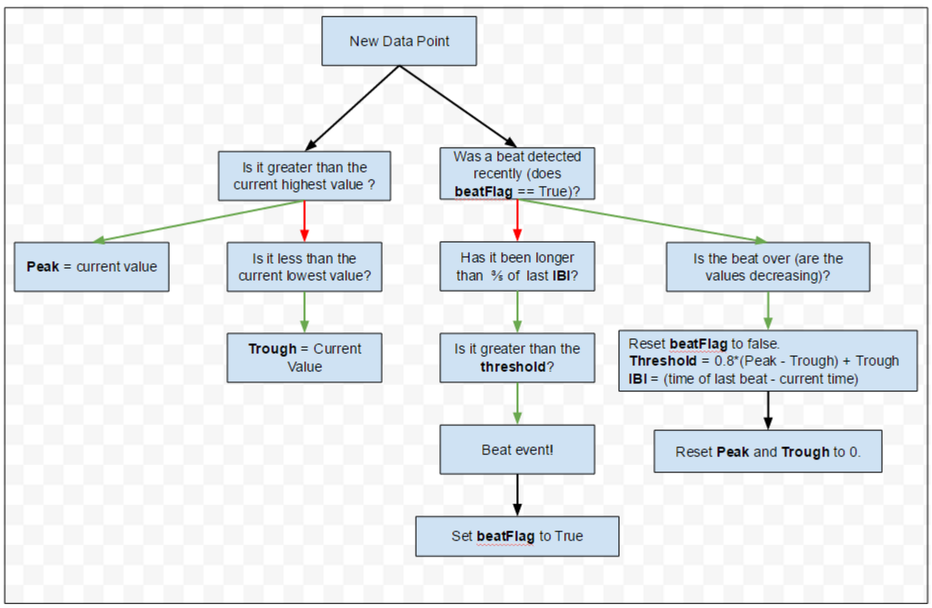

Figure 3.15: Decision making tree that for the final iteration of the heart beat detection algorithm. Key variables are in bold. Green arrows indicate the 'True' option while red arrows indicate the 'False' option. Black arrows are neutral and indicate an automatic flow.

3.4.3 EMG

The Arduino code for the EMG involves a smoothing function and magnitude detection algorithm. The smoothing function is based on a running average algorithm which computes the average over a desired number of data points in real time. Appendix — shows the Arduino code, and the “readingsEMG” is the variable which holds the length of the average index. The magnitude detection algorithm is used to normalize the user’s muscle contraction to a set value between 0 and 100. When the program is initialized, a prompt is sent to the user to relax their muscle. The electrical potential measured in this interval is noted as the minimum voltage, and it is set as the zero magnitude. The user is then prompted to flex for a set amount of time, and the maximum voltage measured here is set to the 100 magnitude. After this initialization period, any voltage from the muscle contractions of the user is measured between this 0-to-100 scale, which correlated to an equivalent range for a musical parameter in the MIDI synthesizer software application.

3.4.4 Breath

A smoothing function using the same running average algorithm as the EMG is implemented on the signal to smooth out any additional noise in lower frequencies. The result is a consistent sine wave which oscillates with low latency from the user’s inhale and exhales. The slope of this signal is taken, leaving rises in the processed signal above the x-axis, and falls in the signal to be below the x-axis. A 0 or 1 value is printed to the Arduino’s serial if the signal is positive or negative, respectively, which corresponds to an inhale or exhale. Experimentation found that this breath rate processing algorithm is reliable to up to 110 breaths per minute, far more than a typical user would realistically have, even during events of physical exertion.

3.5 Software Application

The following section will outline the requirements for the software component of the system. These requirements were very important in informing design decisions relating to our application.

3.5.1 Software Requirements

Functional Requirements

1. The software will successfully access multiple channels of incoming ECG, EMG, EEG, and breath rate values in real time.

2. The software will convert the incoming EEG data from the time domain to the frequency domain for analysis.

3. The software will synchronize the signal processing algorithms effectively.

4. The software will detect different physiological events including but not limited to heartbeats, alpha EEG activity, muscle activity, heart beats, inhales, and exhales with negligible delay.

5. The software will map physiological events to musical events, producing audio in real-time. Recommended

6. The software will compute metrics such as average breath rate, heart rate, and alpha concentration

7. The software will be capable of graphing the incoming ECG data in the time domain and the EEG data in the frequency domain

Non-Functional Requirements Critical

1. The software will be easy to use, reliable, and flexible.

2. The music produced by the software will be clearly derived the user's physiology.

Suggested

1. The software will be aesthetically pleasing and easy to use.

Design Constraints

1. The system will be compatible with multiple operating systems

3.5.2 Nontechnical Description of Functionality

The application works by registering specific physiological events. In this case, a physiological event means the following:

1. A heart beat peak in the ECG signal

2. Alpha activity in the EEG signal

3. Muscle activity in the EMG signal

4. An inhale detected through the custom breath rate sensor

5. An exhale detected through the custom breath rate sensor

When our feature extraction algorithms detect one of these events, the program responds by creating music in the form of MIDI.

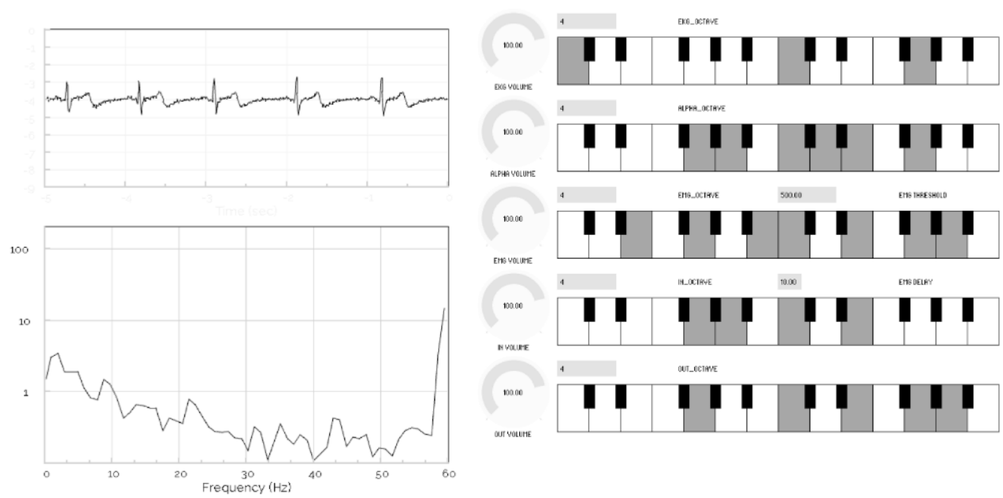

Figure 3.16: The Insula GUI with Biosensor Keyboards

The User Interface

Each of the 5 keyboards on the right hand side of the user interface corresponds to one of the physiological events our algorithms are designed to register. When an event is detected by our system, the keys that are selected (by the user) on the corresponding keyboard are converted into midi notes, which are then sent over a distinct IAC (Inter Application Communication) bus and converted into audio by a software instrument in a DAW (Digital Audio Workstation). Popular DAWs include Garageband, Logic, Pro Tools, and Ableton.

The interface is designed to be minimal – a simple set of controls with which the user can achieve a great deal of flexibility through.

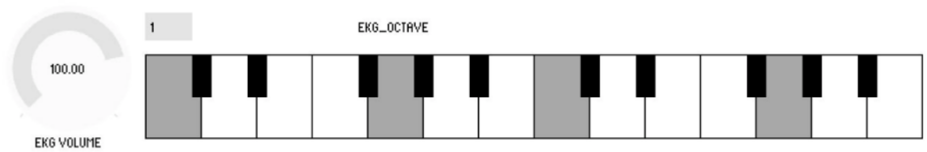

Figure 3.17: An Individual Biosensor Keyboard and Volume Control

The user interface controls for each physiological event:

1. Piano Keyboard: Enables the user to select and deselect the notes triggered by the corresponding event on the universal understood visual representation of a piano keyboard.

2. Octave Slider: The octave slider above the keyboard enables the user to select the octave of the selected notes.

3. Volume Knob: The knob to the left of the slider controls the velocity of the midi notes created when the event is detected.

The Graphs

The graph in the top-left is a time-domain plot of the ECG signal. The graph on the bottom-right is a frequency-domain plot of the EEG signal. The graphs provide a real-time look of the EEG and ECG signals, and have the added benefit of being able to verify the signals are being harnessed correctly by the OpenBCI hardware when our application is running.

3.5.3 The Evolution of the Application

The original concept was for the software to be "hands-off", in that the user would simply strap into our device and start the system. So, for the first complete iteration of the application, all of the music produced by the system was entirely programmatic. The user had no control over the harmony produced by the different physiological events.

At this point, we reached a standstill and faced the following difficult challenges:

- How do we make the music that feels representative of the human body?
- How do we add enough variation such that the music is interesting and engaging?
- How do we cater the music to our audience?

Experimenting to solve these problems became an extremely arduous and somewhat stressful process. Every time we wanted to try a different set of musical chords, even with only a note different, it was necessary to recompile the entire application, configure the hardware or test file, and run the program.

After struggling with this process, it became clear that the development process would be a lot more efficient, and more enjoyable, if there were some user interface elements that enabled changing the harmony produced by the system while it's running. After implementing the keyboard model detailed above, I found myself really enjoying testing the application, eager to try new combinations of chords. After discussing as a team, we decided that framing the application as a "tool" or musical instrument – providing the user with controls and flexibility – was a much more accessible and freeing model for Insula.

3.5.4 Technical Software Description

Design Decision: Processing

We wrestled with a multitude of different software approaches. The main one that we have since departed from has to do with leveraging the power of open source eeg signal processing tools such as Neuromore and OpenViBE, which include signal processing algorithms proven and tested in formal research settings. We ultimately found that while these tools offered a great deal of functionality, they didn't provide us with the necessary flexibility. More specifically, we found it was difficult to process multiple types of biosignals (ECG and emg in addition to eeg). Using these tools would also require us to send live biodata (or values indicating results of the biosignal processing) most likely using the protocol Open Sound Control in order to create an application in a different software development environment (which we would need to do in order to generate sound and audio). We ended up deciding that for the sake of portability, ease of use, and consistency, it was better to build the product entirely in one software development environment. While this forces us to re-implement very low level and complex features that have already been perfected, we can share our project with others in such a way that there is little installation and configuration in order to run the application. To achieve these specifications, we've elected to use Processing, a comprehensive programming language built on top of Java, which includes a lot of tools for audio and visual generation. More importantly, the developers of OpenBCI have built an open source example application, which accesses the raw OpenBCI data for visual output, so we can adapt this functionality to suit our needs.

We carefully evaluated many different possibilities for creating a software application to meet the above requirements.

After careful consideration of Open Source Libraries, different programming languages, and application structures, we elected to use Processing. Processing is both an integrated development environment and open source programming language created by the MIT Media Lab. We elected to use Processing for the following reasons:

1. As Processing is built on top of Java, applications built using Processing can be rendered into Java applets, which are compatible with Windows,

OS X, and Linux machines.

2. Processing is proven to be effective for artistic and experimental use cases.

3. Supports built-in serial Arduino communication

4. Open Source Libraries built for Processing help meet important low level requirements including:

    - OpenBCI hardware communication / initialization
    - Real-time access to incoming data
    - Automatic FFT applied to incoming data
    - Time and Frequency domain graphing mechanisms

5. Support for Midibus fulfills the requirement of producing music via MIDI messages

Application Structure

Constraints of Processing

A big part of the design process for this application has been working within the constraints of how Processing applications are structured in order to achieve the required functionality.

Processing is built for the simple use case of displaying active visuals in motion onto the screen. Whereas most conventional application architectures are event-based, in that the application produces its functionality in response to user events, Processing applications operate in a unique way. In Processing, all function calls must originate from a dedicated draw() method, which, if implemented, is automatically called n times a second, where n is the current frame rate of the application. It is important to note that this frame rate automatically adjusts to the performance of the processor, but is normally in the range of 27-30 frames per second.

Synchronization

In our case, we are taking in data via the OpenBCI hardware at a much faster rate than the frame rate for the application, so we must synchronize our filtering such that we accurately sample the incoming data, and effectively perform translation into the Frequency Domain despite the variability of the frame rate.

Draw()

Thus, the draw() function is our entry point to accessing all of the data that has been collected (since the last frame), filtering the data, outputting sound, and updating the visuals on the screen.

Application Structure

The application is broken up into a set of classes and tabs. Tabs are individual .pde (processing development environment files), which are often used to separate classes, but they can also be utilized to group functions, which are made globally accessible by default.

The main tab for our application, Insula, is responsible for configuring the application and interfacing all of the application's modules together. Insula is the ‘center of control’ for the application. It contains all of the synchronization setup, the main draw() function for the application, and takes care of starting and stopping the flow of data from the board.

Hierarchical Model (top-down)

We approached the structuring of the application with a hierarchical object-oriented model. This approach emphasizes abstraction, so each layer in the hierarchy is only passed the information it needs in order to do its job.

Insula	Main class / center of control for the application - Communicates with hardware - Passes the values along to Channels - Containing tab maintains many important global variables
Channels	- Defines OpenBCI pin indices for EEG and ECG, and passes along ECG time-domain values to beat detection algorithm and EEG frequency-domain values to alpha detection algorithm (in the Features Class) - Parses arduino messages and passes along EMG and Breath Rate in the Features class
Features	- Implementation of feature detection functions - When a “feature” or physiological event is registered, play() is called on the appropriate Instrument (one Instrument for each event)
Instruments	Represents the keyboard channels in the User Interface Defines and Initializes an MidiBus object, which correlate to distinct IAC busses (IAC busses are defined in the IAC Driver settings in the Audio Midi Setup utility on Mac machines) Maintains a list of midi notes which are sent over the MidiBus to a Digital Audio Workstation (DAW)

Figure 3.18: The Top-Down View of Insula’s Application Structure

Chapter 4

Engineering Standards

4.1 Ethics

Our device has been designed with the benefit of humanity at large in mind. It has potential for use in many areas of this pursuit, such as:

1. treating certain disorders of the brain, (see literature review)

2. carrying out basic medical diagnostic tests

3. serving as a promoter of calm states of mind to reduce stress

During the process of creating this device, the team has been referring to the IEEE Code of Ethics as a set of ethical guiding standards. They can be found in the Appendix. Our device is creating an interface between a human and a computer, and while this has stereotypically been a topic of concern, particularly in media over the past century, our intention is explicit - to help users become more aware of their own biology, as well as their ability to influence it. This is a contrast to much of technology which claims to make life "easier" but primarily distracts and disconnects us from self-awareness.

4.2 Health and Safety

One important aspect of our device design which concerned Health and Safety was our choice to make the device wireless. In our original design, the user was indirectly connected to a computer's power supply via a USB cable connected to Arduino. This represented a threat to health and safety should the device or the computer connected to it malfunction and cause a large amount of current to be humped into the device.

To curtail this threat, the Insula design shifted to use a wireless method of communication between Arduino and the output computer. This not only made the device safer, but also easier to use and move with.

4.3 Usability

It was our team's intention to make Insula easy to put on and use, as well as be customizable. While it is still in its infancy, our team has come face to face with the design balance between customizability and ease of use. The simpler and "easier to use" one makes a device, the more one sacrifices the ability of a user to customize it.

In this trade off, the team chose customizability over ease of use. The reason for this decision was that the highest priority to our team was to emphasize the potential capabilities of our device. By making it customizable, we freed our audiences to be able to envision how they might see the device being used, and we received great feedback in the forms of numerous use-cases as a result.

Further progress is needed in order to align our intention of creating something easy to put on and use with the reality of our hardware. This will be detailed in the Future Work section of the next chapter.

4.4 Technology and Society

With wearable technology on the rise, Insula is an endeavor to further enable the growth of technology as it relates to the human body and its functioning on a day-to-day basis, and as mentioned in the previous section, there are many possible use-cases for Insula.

Insula has potential to develop into a self-diagnostic tool which enables anyone to examine their biological state and detect health issues as present in high heart-rate, irregular breath patterns, etc, without the need for a doctor.

Another possible use case brought forth during the first official presentation of the Insula project was that it may be used as a next-generation polygraph or lie-detector. Given that the device is taking so much data from the body, fluctuations of this data under the presence of questions designed to ascertain a lie may indicate one way or another whether or not a given person is telling the truth.

4.5 Manufacturability

Our system, as it was presented at senior design conference, would be difficult to manufacture, as it is a minimum viable prototype. It uses multiple hardware platforms (Arduino and OpenBCI) working separately, is held in a fanny pack, is taped and superglued together in places, and tends to look like a rat's nest of wires. While this works as a prototype version, it is not suitiable for a consumer level, yet.

That said, increasing manufacturability is a primary concern moving forward. We will do this by refining our device design as a team as we move forward. In order for this device to have a tangible impact, it must be scalable for many people to use and experience.

Chapter 5

Conclusion

5.1 Summary of Project

The goal of Insula is to create a device which uses a combination of multiple passive biosensors to produce biophysical music, that is, music generated by the collection and manipulation of biological signal data. The device we created fulfills this requirement.

Insula is a wearable device that translates bioelectricity into audio feedback, with the goal of making this information available, digestible, and ultimately useful to a broad market. Insula will simultaneously monitor multiple systems of the body, including the brain, the muscular system, and the heart.

5.2 Final Results

The Insula system is successful at creating audio feedback from biosensor information. The EEG, EMG, Breath, and ECG all work simultaneously and their respective feature detection algorithms consistently report accurate physiological events. These events are correctly digitally parsed into MIDI information and fed properly into the digital audio workstation of the user's choosing (Apple's Logic in our case, for testing) to create the audio feedback. Improvements to the results are outlined in the future work section.

5.3 Evaluation of Design

We have built an integrated model to assess a user's physiology in real time and create a generative music feedback loop. The system works as per the goals and vision of the original Insula product, and fulfills the design requirements we set out to create. However, the model we have created is a prototype. The system is complementary wireless (from the computer), but the current model is clunky when attached to the body and not fit to go to market. The processing, application, and hardware improvements needed to get Insula to this stage are outlined in the Future Work section. The current design is successful as a minimum viable prototype, but improvements can be made to make the design sleek and more user friendly.

5.4 Impact

The impact of the Insula project addresses key advances in the health technology space. The rise of wearable technology, marked by break-out products like the Fitbit for health, the Muse headset for mindfulness, and the Apple Watch as a personal assistant, demands new ways of thinking about technology and human interaction. Just like with the advent of the personal computer in the 1970s, new technologies call on developers and inventors to think uniquely about how consumers can interact with new products for maximum benefit. The goal with new products should always be maximizing both the quality of the user experience and the effectiveness of the product.

Insula has been built at an essential time, as wearable technology is just starting to penetrate the market and find its uses and niches. The majority of products currently entering this space, as of the writing of this thesis in 2016, are geared towards health or meditation. Health sensors typically pick up heart rate, step count, mileage, and occasionally muscle data, which the mindfulness apps use EEG to track pertinent brain waves. The impact of Insula comes by combining these two paradigms, by integrating multiple sensors, and using audio feedback to enhance user mindfulness. Multiple sensors allow the user to get more dynamic and holistic information about his or her physiology, while the music feedback opens this data into a medium which is understandable to all walks of people and cultures. Insula has proved to be an integrated model of accurately assessing the body holistically in real time, while making the biodata output understandable and interesting to a diverse array of users. This two-fold end result sets Insula apart from other wearable technologies, which typically only satisfy the first goal. In summary, Insula is helping shift the thinking of wearable technology to focus on user experience and interaction, while still maintaining accurate data collection.

5.5 Future Work

Insula is successful attempt at creating an integrated model to assess the body holistically in real time, and make an understandable and interesting output for the end user. The next steps in refining and expanding the technology are outlined below:

1. Hardware: The hardware of Insula can be further refined, simplified, and packaged. What we have created from September 2015 to May 2016 has been the version 1 prototype. Further refinements include building our own microcontroller which only uses the elements we need, and is one single circuit board (opposed to the 4 we have now). These will minimize the components needed, allowing the hardware suite to fit into a smaller package which can easily be the size of a wallet and fit conformably on the user. This will also reduce the cost of the overall system, especially if we can design and print the entire PCB.

2. Sensors: Additional sensors can be integrated, including an accelerometer for movement and a more comfortable EEG headset.

3. The sensors can be integrated into an all-in-one shirt using conductive textiles. This increases user friendliness, operations, and avoids the need for wires.

4. Using a MIDI controller as the final output creates flexibility for the user, because the digital output can be used to not only control musical parameters, but those of actuators as well. These actuators can be motors, to control prosthetics or even a laser light display for performance arts and concerts.

5. The software application and GUI can be improved to easily work on multiple operating systems and DAWs (digital audio workstation)

5.6 Lessons Learned

In addition to each team member learning more about electronics, software development, microcontrollers, and bio-sensing, there were other, less technical lessons learned. The primary is more understanding about the nature of research and development. The Insula team spent a long phase in research, which reduced the available time to develop the technology before the final deliverable date. Developing technologies takes significant time to experiment, test, iterate, source materials, and explore alternate options when the first does not work. Overall we were able to build a working system in time, but additional time in the development phase would have allowed the team to further improve the product before the deliverable date.

Chapter 6

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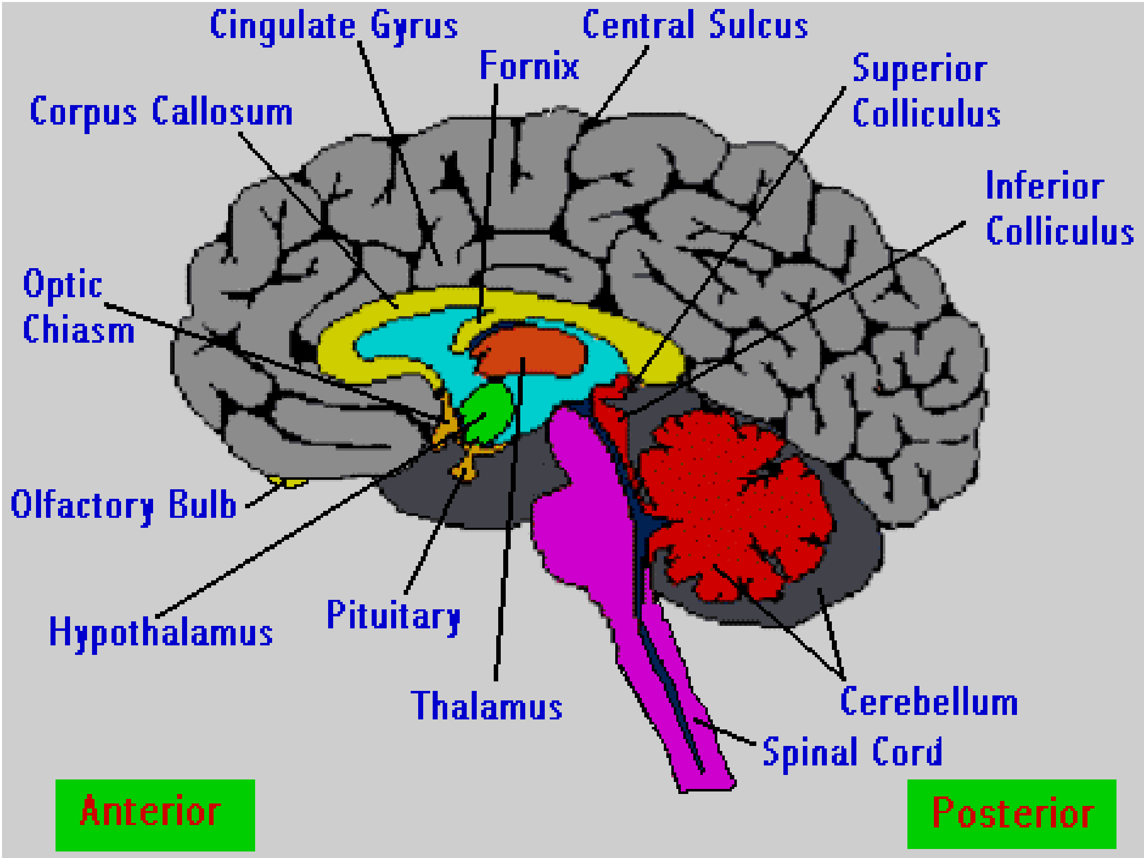
Appendix A

Appendix

A.1 STSCheatSheet of the Brain



Cheat Sheet for Neurofeedback

Steven Warner, Ph.D.

Miami, Florida

01/2013

Cheat Sheet of the Brain – Synthesis for Neurofeedback

Table of Contents:

LEFT HEMISPHERE OF THE BRAIN	RIGHT HEMISPHERE OF THE BRAIN
Dominant hemisphere **Analyzes** – reduces a complex concept or process into its individual components. Detail oriented. **Thinks sequentially** – i.e. one word after another, one note after another. **Thinks linguistically** – perceives, comprehends, stores in memory, formulates and expresses. **Thinks logically**, good at math and analytical reasoning. Verbal memories. Men are stronger with spatial abilities using both sides of the brain; directions, maps or puzzles Beta tends to be higher Theta roughly equal left & right	**Synthesizes** – takes components and combines them into an integrated whole. Experiences the process in its entirety. **Thinks spatially/holistically** – putting puzzles together, hearing the musical chord. Intuition and insight. **Perceives, comprehends and expresses visual and auditory social cues** – reading faces, remembering places, creating facial expressions, comprehending and creating vocal intonation. Creativity, empathy, early self-concept. **Experience and express emotion** – anger, rage, anxiety. Mood regulation emotional – contextual. Alpha tends to be higher

Specificity to sites is slightly misleading – these are best guesses and all functions are a result of the interaction of many areas. The typical site is differentially engaged in 40% of behavioral domains.

Prefrontal Cortex Fp1, Fz, Fp2

Executive functioning – establishes goals, inhibits information extraneous to the goal directed planning process, plan and make decisions, working memory. Prefrontal lobes have connections to the amygdala. Self-regulation, initiation, social-emotional behavior in social context, recognition and production of expression of language (prosody)

Decrease in left prefrontal activation may reflect depressive experience where increase in right prefrontal activation may reflect anxieties.

Prefrontal lobes have neuronal networks leading to the amygdala.

Autonomic Nervous System regulation

Attends to internal and external stimuli,

Determines the amount of attention that will be distributed among competing stimuli.

Supervisory Attentional System - Sustained attention.

Motor Control and Programming

Calls up memory and utilizes it

Ability to inhibit behavior appropriately in complex social contexts

Delayed gratification

Mental flexibility

Understanding the concept of past, present and future.

Provide awareness of what is rewarding and pleasurable

Regulation of emotions (modulate and inhibit impulses)

Organising, creative, problem solving

Ability to learn from experience. Reality testing

Development of personality

Attachment, conscience, empathy

Fz – frontal eye fields, motor, focus and action observation.

(Fpz – emotional inhibition, modulation of emotional (sensitivity) and behavioral responses, motivation/attention.)

Fp1 & F3 – logical, detailed attention, the organization of responses (like a conductor), semantics	Fp2 & F4 – emotional/contextual attention

Fp1 - verbal retrieval. Visual working memory, verbal analytical and approach behaviors	Fp2 - Face and object processing, gestalt and context, episodic memory (when overactive may correlate with irritability, impulsivity, tactless, manic and panic behavior)

Frontal Lobes

Higher executive functions

Attentional gating. Decision making. Problem solving, memory, social awareness, character, motivation, planning, judgment.
Frontal lobes are responsible for immediate and sustained attention, social skills, emotions, empathy, time management, working memory, moral fiber or character, executive planning and initiative. They identify problems and may send them to other parts of the brain for resolution.

The brain is not just a cognitive processing organism; it is also the seat of our conscience. Emotions, morals and social self cannot be isolated to frontal lobe activities; other deeper structures are also involved. There is a relationship between the frontal lobe and the amygdala. The frontal cortex is responsible for the brains most complex processing and has the heaviest projections to the amygdala, and the two combine to form a network that is the social brain.

F3 & F7 - Approach behavior, engagement, interest, mood regulation, processing of positive emotional input, conscious awareness. Frontal mirror neuron system – empathy and intention of others. F3 – judgment, planning, sustain attention, inhibition of responses, verbal episodic memory retrieval, problem solving, sequencing, deducing facts to conclusions. F7 - Creates and controls output of spoken and written language, visual and auditory working memory, selective attention Broca's area (word retrieval,	F4 & F8 - Avoidance behavior, withdrawal, impulse control (important links to the amygdala). Emotional tone variations (motor aprosodia) F4 – inductive creative, inductive emotional, metaphorical thinking, short-term retrieval of spatial-object memory, vigilance, selective and sustained attention. F8 – spatial and visual working memory, gestalt, sustained attention, conscious facial emotional processing, prosody Empathy conscience. Feeling sense of right and wrong. Emotional gating. Vigilance area.

semantics, verbal understanding, speech) Divided and selective attention	Apprehension, disinterest Sustained and selective attention Processing of anger, rate, anxiety, fear. Regulation of aggressive and sexual impulses

C3, Cz, C4 Central Strip

The sensory and motor cortices run parallel to each other and are divided by the central sulcus. The two cortices combined are called the sensorimotor cortex.
The sensory cortex alone is the primary somatosensory cortex or the somatosensory cortex: spatial discrimination and the ability to identify where bodily functions originate. Responsible for both the external senses of touch, temperature, pain and the internal senses of of joint position, visceral state and pain.

The primary motor cortex may be called just the motor cortex - conscious control of all skeletal muscle movements. Skillful movements and smooth repetitive operations such as typing, playing musical instruments, handwriting, the operation of complex machinery and fluid speaking. It is the hub and switching station between voluntary muscles of the body and the brain.

Cz – somato-sensory association cortex (? Hub of affective limbic system).

Sensory-motor functions, short term memory

Awareness of body, body position, body movement, co-ordination of sensory input with motor output.

Gross motor activity, walking, throwing a ball

Fine motor movements – pen skills, needle threading, typing, speaking.

C3 – hand and digits (with F3 – handwriting and inhibit or execute action), audition, happiness,	C4 – cognition of music, reasoning/decision making and emotional/feeling, and in addition, disrupts the process of basic body

syntax	signaling, happiness & sadness

The Sensorimotor cortex not only divides the anterior from the posterior, but they also serve as a junction that coordinates movement that is also in part guided by sensations.

Temporal Lobes T3 & T4

Auditory Association cortex; phonetics, letters to sound, grasping the whole picture vs. sensing everything in fragments (may be dysfunctional in autism), episodic memory, emotional valence and regulation (temper). Without clear left hemisphere dominance, dyslexia and stuttering may occur. Because women have up to 30% more interhemispheric connections, they manage dyslexia better and understand interpersonal emotions better.

T3, T5 (left) Wernicke's – comprehension both verbal and reading visual perception of what an object is processing integration and perception of auditory input comprehension of auditory and visual perception (reading and word recognition) long term memory – auditory (verbal) and visual linguistic perception and comprehension "Inner voice" positive mood	T4, T6 (right) – conscious emotional and physical awareness (insula), sense of direction visual memory & visualization, categorization sound voice intonation perception, music facial recognition spatial and facial perception - social cues T4-T6 Central Strip (Temporal-Parietal junction RHS – copying emotional tones, comprehension – innuendo & nuance, non-verbal memory visual perception of what an object is (object recognition) symbol recognition long Term memory emotional content (anxiety) due to proximity to amygdala and hippocampus

Parietal Lobes P3,Pz, P4

Organization, integration, and synthesis of auditory, visual perception, and kinesthetic inputs, orientation, cognitive processing and attention.

The parietal lobes solve the problems that the frontal lobes conceptualize. Labeled the "association cortex".

Pz - Integrating somato-sensory information with posterior visual perceptions, working memory

Posterior parietal cortex - sense of direction, Balint's syndrome...the client cannot attend to multiple objects simultaneously, can't shift attention from one location to another, or perhaps one sensory modality to another.

Parietal and Occipital – procedural memory

Posterior Pz may involve long term memory, sensory integration and some quick decisions in crisis situations.

Parietal spindling beta reflects sensory hypersensitivity or sensory defensiveness, auditory, visual and kinesthetic.

P3 - Language processing, integration of self, logical reasoning and memory, imagination, spelling and short term memory, math calculations, naming objects, complex grammar, sentence construction and math processing (right side body awareness)	P4 - Visual-spatial sketch pad, image and spatial processing, facial decoding, integration with environment, spatial memory, perhaps dysfunction effects self-concern, map orientation, knowing the difference between right and left, self in space, music, body image, physical act of dressing. (left side body awareness)

Occipital Lobes O1, Oz, O2

Visual association cortex. Visual processing, procedural memory, dreaming, visual perception.

Visual field, helps to locate objects in the environment, see colors and recognize drawings and correctly identify objects, reading, writing and spelling.

Increased activation of the occipitals may reflect brain stem issues (cerebellum and involutional body movement)

Because the occipital lobe borders on the parietal and temporal lobes, EEG abnormalities in posterior locations in those two lobes, often extend into occipital lobe regions

Oz – Hallucinations

O1 - memory encoding with semantic tasks	O2 - perception, vision, color (somewhat shape and motion)

IMPORTANT FUNCTIONS VIA LOBES AND SITES - TRAINING IMPLICATIONS

Frontal Lobes

Behaviors and symptoms:

Oppositional defiant and antisocial behaviors. This behavior may parallel excessive EEG slowing, and inadequate CBF throughout other prefrontal areas as well-especially Fp1 and Fp2.

Clients with excessive fear as a result of trauma, anxiety, and neglect may have an overactive amygdala.

Training along the anterior dorsal Fz and ventral Fpz may have an impact on social behavior and moral fortitude (dysfunction shows as irresponsible behavior, lack of appropriate affect, euphoria in some and incorrect expectation in others).

Training in the right prefrontal cortex may lead to a reduction in fear as well as create a sense of calm and well being.

Checking for prefrontal lobe problems often involves testing. Even without testing, look for: clients appear to be in a fog, unable to concentrate. They get into trouble in school or with community authorities. They may be fearful, have difficulty with ethical or moral issues, lack empathic ability, or lack social skills. Difficulty in completing administrative tasks, unmotivated, disconnected. Inattention, poor planning or judgment, slow reaction time, lack of social awareness and poor impulse control.
Negative, depressed or anxious...check out frontal asymmetries.

SENSORY MOTOR CORTEX C3, C4, Cz

Behaviors and symptoms:

Training along the SMR is implied for stroke, epilepsy, paralysis, ADHD, and disorders of sensory motor integration.

Clients who have difficulty seeing the logical sequence of cognitive tasks may benefit from neurofeedback training along the LH sensory cortex (C3). Training along the RH sensorimotor cortex (C4) may invoke feelings, emotions or calmness.

Temporal Lobes

If "hot" avoid training initially due to issues of reactivity (sensitivity to external or internal input, emotion)

Behaviors and symptoms:

Left mid-temporal zone problems could reflect difficulties in keeping up a conversation.

Right temporal lobe problems may reflect inability to recognize intricate rhythmic melodies; appreciation for music.

Mid-temporal extending into the hippocampal lobes ...episodic memory, such as functional tasks; remembering to pay the bills, fill the gas tank, where the keys are, how to play baseball, where glasses, etc.

Because of the temporal lobes proximity to the amygdala, it could result in angry or aggressive behavior.

EEG slowing in the temporal lobes is often associated with concussions since head injuries, regardless of the site of the impact, often involve scraping of the temporal lobes along the inner part of the sharp, bony, middle fossa. Problems with temporal lobe slowing are the most common type of EEG abnormality......major pathology changes in aging, anoxic conditions, head injury, and many other etiologies found in the temporal lobe, especially in the depth of this lobe the amygdala and hippocampus.

Cerebral Blood Flow in the temporal lobes (especially R) for subjects with anxiety and panic disorder. Mild anxiety increases CBF; severe anxiety reduces CBF values and cerebral metabolism.

Parietal Lobes

Behaviors and symptoms:

Clients may have more car accidents because they cannot attend to both sides of the visual field. May have difficulty playing computer games which require a left to right scanning process. Draw pictures and the left of the picture seems to have something missing...may be a deficit in right parietal lobe.

Difficulty following directions to the office, failure to recognize a simple tune, can't remember faces, easily gets turned around and gets lost...then look at the parietal lobe as well as the right posterior temporal lobe.

Ask client to write a few sentences. Draw a simple picture, play " monkey see, monkey do", do a few simple math or word problems. How well do they perform? How accurate is the picture? How difficult is it to follow hand and body movements? How easy were problems solved, or not at all?

OCCIPITAL

Behaviors and symptoms:

Difficulty with visual memories and accurate reading require accurate vision. Traumatic memories that accompany visual flashbacks are often processed in the occipital lobes.
Visual agnosia....inability to perceive and draw complete objects.
Simultaneous agnosia....inability to see multiple objects at the same time.

Problems with writing...cannot trace the outline of an object, or join the strokes together during writing, if they see the pencil point they lose the line, or if they see the line they can no longer see the pencil point. Difficulty coloring or other visual spatial activities.
(Also consider posterior parietal lobes for visual spatial problems).

Adults who have strokes or TBI

Clients who have PTSD may benefit from training in the occipital lobes. There is a unique connection between the visual cortex and the amygdala related to PTSD. Practitioners often place sensors on the visual cortex when doing deep states training.

DEEPER BRAIN STRUCTURES - FUNCTIONS

The Limbic System

This is power-packed with function even though it is only about the size of a walnut. It sets emotional tone, controls motivation and drive, holds emotional memories. The female limbic system is larger relative to the size of the brain than is the male.

Hypothalamus

One of the busiest parts of the brain. It is mainly concerned with homeostasis. It regulates hunger, thirst, pain response, pleasure, sex drive, sleep, the ANS and thus control of the hormonal system. It activates the fight or flight system.

Amygdala

Provides emotional content to language, intonation, sound of voice, social emotion, guilt, shame. Detection, judgment (evaluation & magnitude) of fear, sadness (not happiness). Dysfunction shows as social disinhibition. Stores unconscious memories. Mediates depression and hostility/aggression.

Hippocampus (beneath the temporal lobes)

Short and long term auditory and visual (emotional) memory conscious (LH). Sound-voice intonation, memory, and spatial-facial memory (RH).

Septal Nucleus

This acts in conjunction with the hypothalamus and hippocampus particularly in relation to internal inhibition and the exerting of quieting and dampening influences on arousal and limbic system functioning.

Cingulate Gyrus (Fpz, Fz, Cz, Pz)

Being able to shift ones attention from one subject to another. Mental flexibility. Executive functions. Adapting within changing circumstances/seeing options. Being co-operative in a social context.

Anterior cingulate gyrus - the HUB affect/emotional regulation and limbic system control. Mental flexibility, cooperation, attention, helps the brain to shift gears, and the young child to make transitions, helps the mind to let go of problems and concerns, helps the body to stop ritualistic movements and tics, helps contribute to the brain circuitry that oversees motivation, the social self and the personality. Is closely aligned with the amygdala. Here, imagination, motor learning, fear and pain.

Posterior cingulate gyrus....closely aligned with parahippocampal cortices and shares in the memory making process, provides orientation in space, as well as eye and sensory monitoring services. The division between the anterior and posterior is generally considered to be at Cz.

Training at the vertex, Cz, influences three cortices simultaneously, somatosensory, motor and cingulate.....the cingulate is concerned with emotion/feeling, attention and working memory. They interact so intimately that they constitute the source for the energy of both external action (movement) and internal action (thought, animation, and reasoning).

The "hot" cingulate means it is overactive and causing problems such as OCD, ADD/ADHD and Tourette's syndrome.

ADD/ADHD - the disorder can manifest itself with, or without hyperactivity. Components include inattention, distraction, hyperactivity and impulsivity. Several different brain localities may be suspect when assessing ADD/ADHD. The cingulate gyrus and the anterior medial region may be the first place to look.

Flexibility and "Inflow".

Thalamus

Connects sensory organs to areas of primary sensory processing – eyes to visual cortex of the occipital lobe. Ears to primary auditory cortex of the temporal lobe. Body sensation and position to primary somato- sensory cortex of the Parietal lobe. Connects the cerebellum to the motor strip. Sets overall tone or level of excitation for the entire cerebral cortex. Virtually all inputs ascending to the cerebral cortex are funneled through the thalamic nuclei - the gateway to the cortex.

Reticular Activating System

This is the centre in the brain. It is the key to “turning on the brain” and seems to be the centre of motivation. Keeps the brain alert, awake and receptive to information.
It serves as a point of convergence for signals from the external world and the internal environment.
The R.A.S. is the centre of balance for the other systems involved in learning, self-control or inhibition.

Brain Wave Frequencies:

Fast waves are not synchronous – engaged with the world.

Gamma brainwaves are very fast EEG activity above 30 Hz. Although further research is required on these frequencies, we know that some of this activity is associated with intensely focused attention and in assisting the brain to process and bind together information from different areas of the brain.

Gamma is measured between (36 – 44) Hz and is the only frequency group found in every part of the brain. When the brain needs to process simultaneous information from different areas, its hypothesized that the 40 Hz activity consolidates the required areas for simultaneous processing. A good memory is associated with well-regulated and efficient 40 Hz activity, whereas a 40 Hz deficiency creates learning disabilities. When trained it improves memory, language and effortlessness in learning.

Gamma (40 Hz): Subjective feeling states: thinking; integrated thoughts, learning.
Associated tasks & behaviors: high-level information processing, "sensory binding." Physiological correlates: associated with information-rich task processing.

Beta brainwaves are small, relatively fast brainwaves (above 13–30 Hz) associated with a state of thinking, mental, intellectual activity and outwardly focused sustained concentration. This is basically a ‘‘bright-eyed, bushy-tailed’’ state of alertness. Activity in the lower end of this frequency band (e.g., the sensorimotor rhythm, or SMR at Cz) is associated with relaxed attentiveness. If someone is exceptionally anxious and tense, an excessively high frequency of beta brainwaves may be present in different parts of the brain, but in other cases this may be associated with an excess of inefficient alpha activity in frontal areas that are associated with emotional control. If beta is deficient, either all over or in small areas, the brain may have insufficient energy to perform tasks at peer group standards.

Beta activity is fast activity. It reflects desynchronized active brain tissue. It is usually seen on both sides in symmetrical distribution and is most evident frontally. Beta should be higher on the left than on the right. Increased beta asymmetry in the right hemisphere is indicative of anxiety. Beta hyper-coherence may indicate anxiety, panic attacks, and test anxiety. It may be absent or reduced in areas of cortical damage. It is generally regarded as a normal rhythm. It is the dominant rhythm in those who are alert or anxious or who have their eyes open. Beta fast is the state that most of brain is in when we have our eyes open and are listening and thinking during analytical problem solving, judgment, decision making, processing information about the world around us. Dominant frequency beta may indicate that there is excess norepinephrine. Increased beta alone is often indicative of withdrawal from social interaction (when theta and alpha are lower). Increased beta at Fp2 and F3 simultaneously can be indicative of the patient hiding all feelings and emotions (flat affect may be seen). Increased beta and decreased alpha in frontalis is indicative of agitation, being controlled by anxiety, feeling overwhelmed, and impulsivity with explosiveness.
The beta band has a relatively large range, and has been divided into low, midrange and high.

Low Beta (13-15) Hz: Could be called hi alpha, formerly "SMR":(Sensory Motor Rhythm when at C3, Cz, or C4). The alpha wave of the motor system, maximum when body is still.
Subjective feeling states: relaxed yet focused, integrated.
Associated tasks & behaviors: low SMR can reflect "ADD", lack of focused attention Physiological correlates: is inhibited by motion; restraining body may increase SMR

Midrange Beta (15-18) Hz: Subjective feeling states: thinking, aware of self & surroundings; Associated tasks & behaviors: mental activity; Physiological correlates: alert, active, but not agitated. Localized activity where work is being done, asynchronous.

High Beta (above 18 Hz): Muscle artifact can intrude here. You tend to inhibit hi beta to decrease artifact.

Subjective feeling states: alertness, agitation, problem solving,

anxiety, worrying, rumination, mental effort.
Associated tasks & behaviors: mental activity, e.g. math, planning, etc.
Physiological correlates: general activation of mind & body functions.

Beta hypercoherence – stress, “traffic jam,” overwhelmed, can’t process activated networks.

Beta hypocoherence – immobilized.

Beta Wave Indicators:

Area	Indicator	Indicator	Indicator	Indicator	Indicator
Frontal	Anxiety Impulsivity (being controlled by anxiety and feeling overwhelmed), and impulsivity with explosiveness, Mood shifts	Pain	Emotional hyper-vigilance and controlling, passive and/or avoidant personality Insomnia Person hides all feelings and emotions (flat affect may be seen)	Fear (increased frontal beta) Aggression (decreased frontal beta)	Increased beta in frontal areas and on the right hemi (the brain is running too fast) may indicate anxiety, OCD, mania and worry
Temporal	TBI			Anger Irritability	
Global	Anxiety ADD Insomnia (insomnia often reveals LoBeta at 5.1/4.5)	Insomnia Muscle tension Headaches	Self-regulation problems		OCD
Posterio	Anxiety	Fibromyalgi	Ruminatio		OCD

r	disorder(s) Rumination	a	n Trauma		Ruminatio n

Slow waves are synchronous.

Alpha brainwaves (8–12 Hz) are slower and larger. Alpha is generated from resonance between the thalamus and the cortex. They are generally associated with a state of relaxation, peacefulness and alertness. Activity in the lower half of this range represents to a considerable degree the brain shifting into an idling gear, relaxed and a bit disengaged, waiting to respond when needed. If people merely close their eyes and begin picturing something peaceful, in less than half a minute there begins to be an increase in alpha brainwaves. These brainwaves are especially large in the back third of the head. EEG investigations of alcoholics (and the children of alcoholics) have documented that even after prolonged periods of abstinence, they frequently have lower levels of alpha and theta brainwaves and an excess of fast beta activity.

Alpha waves will peak around 10 Hz. Good healthy alpha production promotes mental resourcefulness, aids in the ability to coordinate mentally, enhances overall sense of relaxation and fatigue. In this state you can move quickly and efficiently to accomplish whatever task is at hand.

When Alpha predominates most people feel at ease and calm. Alpha appears to bridge the conscious to the subconscious. It is the major rhythm seen in normal relaxed adults - it is present during most of life especially beyond the thirteenth year when it dominates the resting.

Alpha rhythms are reported to be derived from the white matter of the brain. The white matter can be considered the part of the brain that connects all parts with each other.

It is a preferred state for the brain and occurs whenever a person is alert (it is a marker for alertness and sleep), but not actively processing information. Alpha waves are strongest over the occipital (back of the head) cortex and also over frontal cortex.

He traumatized brain idles too fast (in the beta direction), or too slowly (in the theta direction). If excessive alpha coherence is present, the brain may be locked up in alpha and be hard to speed up or slow down. Low alpha may be indicative of anxiety, PTSD, or short-term memory impairment. (Low alpha increases cortisol in the brain, which affects the hippocampus and thus short-term memory). Alpha should be higher in the right hemisphere than in the left hemisphere. Alpha asymmetry and locally increased alpha are indicative of depression. With an eyes-closed map, the normal dominant frequency should be alpha. When the dominant frequency is at 11-12 Hz, it is faster than normal; slower than normal from 8-9 Hz and when 9.5-10.5 Hz it is considered normal. Slow (or low) alpha can be indicative of metabolic problems, toxin-related issues, bipolar disorder/depression, and substance abuse (i.e., marijuana use/abuse). Increased fast alpha in the posterior may indicate emotional rumination.

Alpha has been linked to extroversion (introverts show less), creativity (creative subjects show alpha when listening and coming to a solution for creative problems), and mental work. When your alpha is with in normal ranges we tend to experience also good moods, see the world truthfully, and have a sense of calmness. Alpha is one of the brain's most important frequencies to learn and use information taught in the classroom and on the job. You can increase alpha by closing your eyes or deep breathing or decrease alpha by thinking or calculating. Alpha-Theta training can create an increase in sensation, abstract thinking and self-control. Alpha allows us to shift easily from one task to another. Too much alpha in the right frontal cortex may be associated with defiance in children while a similar amplitude in the left frontal cortex may be associated with a depressed mood state.

Subjective feeling states: relaxed, not agitated, but not drowsy; tranquil, conscious

Associated tasks & behaviors: meditation, no action
Physiological correlates: relaxed, healing

Sub band low alpha: (8-10)Hz: inner-awareness of self, mind/body integration, balance

Sub band high alpha: (10-12)Hz: healing, mind/body connection.

If Alpha is blunted or absent, clients cite poor retention of info and/or poor short-term memory. When Alpha response is non-existent or negative then suspect the possibility of traumatic stress.

When Alpha response is negative at both Cz and O1, suspect emotional trauma.

In most severely emotionally distressed fibromyalgia patients, the QEEG show relatively little Alpha activity and the greatest Alpha power in the group with the least emotional distress (and pain). The more severe fibromyalgia patients, i.e. those with the greatest psychological distress and pain, are most likely those with a history of significant emotional trauma.

Alpha Wave Indicator:

Area	Indicator	Indicator	Indicator	Indicator
Frontal	Depression (alpha asymmetry with more alpha on the left than right) Lack of motivation Lack of right alpha – social withdrawal	Decreased alpha is indicative of impulsivity, being controlled by anxiety, feeling overwhelmed, and impulsivity with explosiveness	ADD Attentional problems	Pain and anxiety
Global	Increased alpha on the left may indicate emotional shutdown	Depression Metabolic issues Substance abuse	Parkinson's may include alpha slowing	Person's energy level is low (esp. when delta is low)
Posterior	Depression, passivity, and avoidant personality	Trauma, PTSD		Fibromyalgia (depressed alpha)

Theta (4–8 Hz) activity generally represents a more daydream like, fantasy prone rather spacey state of mind that is associated with mental inefficiency. At very slow levels, theta brainwave activity is a very relaxed state, representing the twilight zone between waking and sleep. When theta is high, the brain is working overtime to recruit resources (perhaps because there is a lack of nutritive resources available). Generally, when there is increased theta, there may be increases in delta and alpha (all slower waves). Having increased theta and beta is like driving with the brakes on (the brain does not run smoothly).

Persons with Attention-Deficit Hyperactivity Disorder (ADD, ADHD), head injuries, stroke, epilepsy, developmental disabilities, and often chronic fatigue syndrome and fibromyalgia tend to have excessive slow waves (usually theta and sometimes excess alpha) present. When an excessive amount of slow waves are present in the executive (frontal) parts of the brain, it becomes difficult to control attention, behavior, and/or emotions. Such persons generally have problems with cognitive processing, concentration, memory, controlling their impulses and moods, or hyperactivity. They have problems focusing and exhibit diminished intellectual efficiency. Theta is generated through the thalamo-cortical path and reflects resources used in the body, pulled into the brain when needed. Check out one's diet and exercise/health issues. Elevated theta in the posterior of the brain tends to be associated with feelings of calm and well-being.

Theta activity is classified as "slow" activity. It is seen in connection with creativity, intuition and daydreaming and is a repository for memories, emotions, and sensations. Theta waves are strong during internal focus, hyper-vigilance, meditation, prayer, and spiritual awareness. It reflects the state between wakefulness and sleep. Relates to subconscious.

It is abnormal in awake adults but is perfectly normal in children up to 13 years old. It is also present during sleep. Theta is believed to reflect activity from the limbic system and hippocampus regions.

Theta is observed in anxiety, behavioral activation and behavioral inhibition. When the theta rhythm appears to function normally it mediates and promotes adaptive, complex behaviors such as learning and memory. Under unusual emotional circumstances, such as stress or disease states, there may be an imbalance of three major transmitter systems, which results in aberrant behavior. Excessive theta and delta have a slowing effect and the brain is underactive. Lack of blood flow to the brain increases theta and delta waves.

Subjective feeling states: intuitive, creative, recall, fantasy, imagery, creative, dreamlike, switching thoughts, drowsy

Associated tasks & behaviors: creative, intuitive; but may also be distracted, unfocused
Physiological correlates: healing, integration of mind/body.

Theta/Beta Ratios: (greater than 3:1 - constitutes a slow-wave disorder. The normal theta/beta ratio is 2:1 (i.e., theta 8.7 over beta 11.07 = .79 or too much beta). The largest theta/beta ratios are found at Cz or Fz; the smallest theta/beta ratios are found in the temporal lobes. The normal theta/beta ratio at Cz is 1.6:1, and at Fpz is 1.5:1. A high theta/beta ratio is a signature of ADHD. Deficiencies suggest inefficiency in self-quieting, general anxiety, self-medicating and/or distraction oriented behaviors, burnout, depression or poor sleep quality, self-designated alcoholics. When the ratio is too high, look for interpersonal detachment with qualitative aspects of autistic or Asperger's behavior. Look to equalize frontal lobe activity and reduce the theta/beta ratio in the occipital area of the grain.

Theta Wave Indicators:

Area	Indicators	Indicators	Indicators	Indicators	Indicators
Frontal	ADHD/ADD Anxiety	Impulsiveness/ Impulse Control D/O Lack of inhibitory control (when theta is higher on the right front and right hem.)	Foggy headed/L.D. (Unable to grasp concepts, ideas, information)	Emotional: PTSD Depression/Over-whelmed Emotions shut down	Disorganization (when theta is higher on the left front and left hemi)
Temporal			Language processing problems Short-term memory problems	Emotional processing problems	
Global		Decreased delta/theta globally may indicate a person is low energy (esp. when alpha is high)		Emotional processing problems	Trouble with accessing emotional information. Retrieval problems
Posterior	Pain and anxiety. Decreased theta may indicate attentional problems.	OCD/ Perseveration (hard time letting go)	L.D. reading comprehension problems		

Delta brainwaves (.5–3.5 Hz) are very slow, high-amplitude (magnitude) brainwaves and are what we experience in deep, restorative sleep. In general, different levels of awareness are associated with dominant brainwave states. Delta measures do not give clear diagnostic indications. Delta brainwaves will also occur, for instance, when areas of the brain go ‘‘off line’’ to take up nourishment, and delta is also associated with learning disabilities. If someone is becoming drowsy, there are more delta and slower theta brainwaves creeping in, and if people are somewhat inattentive to external things and their minds are wandering, there is more theta present. Often present with learning difficulties.

ADD tends to show high amplitude delta slow waves, excessive theta or a locked in alpha state. Excessive alpha and beta is the brain’s most reliable signature for depression. Depression may show high alpha or beta, excessive coherence problems or poor inter-hemisphere communication.

The lowest frequencies are delta and are generated from the brain stem and cerebellum. These are less than 4 Hz and occur in deep sleep and in some abnormal processes also during experiences of "empathy Delta waves are involved with our ability to integrate and let go. It reflects unconscious mind. Delta is normally the dominant rhythm in infants up to one year of age and it is present in stages 3 and 4 of sleep. It tends to be the highest in amplitude and the slowest waves. We increase Delta waves to decrease our awareness of the physical world. We also access information in our unconscious mind through Delta. Complex problem solving.

Peak performers’ decrease Delta waves when high focus and peak performance is required. However, most individuals diagnosed with Attention Deficit Disorder, naturally increase rather than decrease Delta activity when trying to focus. The inappropriate Delta response often severely restricts the ability to focus and maintain attention. It is as if the brain is locked into a perpetual drowsy state. Parietal delta (P4) affects association and cortex/processing. A delta deficit is indicative of problems with working memory.

Subjective feeling states: deep, dreamless sleep, non-REM sleep, trance, unconscious.
Associated tasks & behaviors: lethargic, not moving, not attentive
Physiological correlates: not moving, low-level of arousal.

Delta Wave Indicators:

Area	Indicator	Indicator	Indicator	Indicator	Indicator
Frontal	TBI	L.D.	Dementi	Parkinson’	Decreased Delta may indicate

			a	s	short-term memory problems
Temporal	TBI	Language Processing Problems			Short-term memory problems
Global	TBI				Emotional processing problems/ADHD/list acquisition problems
Posterior		L.D.			

Biofeedback is the process of learning to control physiological functions by the use of instrumentation. Biological signals are fed to trainees with the goal of gaining mental control over subconscious biological processes. Biofeedback is a self-regulation skill and always rewards the trainee. Trainees learn best when the challenge matches their ability to learn. Training that is too easy or two difficult usually fails to produce change.

When brain-maps are consistently blue (hypo-arousal), the body is winning the battle for resources. When the brain-maps are consistently red, there is heightened stimulation.

Absolute Power – the brainpower available within a particular frequency at each site. The amplitude/strength of the frequency. Microvolts squared.

Relative Power – whether a particular frequency is overpowering other vital frequencies. In proportion to other bands. Distribution of power. Percentage of total power in each channel.

Mean Frequency – average frequency reflects if the bandwidth is within normal operating ranges. Example, alpha should peak around 10hz, and when it peaks at 9.5 hz, individuals may complain of fatigue, being error prone or simply misunderstanding vital input information.

Asymmetry – whether the brain waves between the various parts of the brains are balanced (difference in magnitude between two sites). Excessive activity may indicate an overtiring of brain cells. Insufficient activity may suggest neurons are not firing sufficiently to maintain proper function.

Coherence – How stable the phase relationship is between two sites. The degree of interaction or communication, shared information, between brain sites. Who's talking to whom? The inner self-talk reflecting connecting and disconnecting different parts of the brain to accomplish tasks. A measure of synchronization between activity in two channels.

<u>Hypercoherence</u>: when brain sites are not functioning in efficient interdependent fashion, but rather have too much "cross-talk". Excessive coherence tends to indicate two or more areas of the brain being overly connected or locked together. Too rigid, and this also occurs when the brain builds new neural connections. The brain has become overly dependent on these centers and is not efficiently processing and executing information resulting in poor day-to-day performance. Hypercoherence requires cortical organization while hypocoherence does not.

<u>Hypocoherence</u>: This is called poor inter-site interaction and is associated with diminished cognitive efficiency. Deficient coherence is a sign that the brain is not able to efficiently connect cortical areas to perform specific tasks. Insufficient differentiation inhibiting effective inter-site communication. Learning disabilities may show either hyper or hypo-coherence while serious TBI classically show excessive coherence. This is often found with brain injury, after which clients experience stereotypical, perseverative and inflexible behavior and cognitive processing.

A full Q is required to assess hypocoherence (!)

Phase – reflects how many of the brain's functions are timed events, the energy from one part of the brain arriving at the right moment to perform a task. Excessive phase mean the signals arrive too early (meaning a slowing of connections) while deficiency means they arrive too late. This is a measure of the temporal relationship between two signals. A locking and unlocking of signals. EEG waves are electromagnetic waveforms that move from positive to negative voltage. If two wave forms shift from positive to negative at exactly the same rate, they are in phase. Two wave forms that shift at the opposite rate are out of phase. Areas of the brain that emit consistently in-phase signals are doing so because they are communicating and processing the same information. Consequently, they are referred to as coupled.

Bandwidth microvolt normative distributions at Cz:

Bandwidth	Eyes Closed	Eyes Open
Alpha (8-12 Hz)	16.6 mvl	9.3 mvl
Theta (4-8 Hz)	12.4 mvl	10.7 mvl
Beta (13-21 Hz)	8.1 mvl	6.4 mvl
SMR (12-15 Hz)	5.1 mvl	4.4 mvl
Theta to beta ratio	1.6:1	1.8:1

Normal amplitude of beta tends to be higher than or equal to high beta, while the normal amplitude of theta tends to be greater than delta. Theta is still highest at Pz (EO).

Contributions from Soutar & Longo ("Doing Neurofeedback")

Drug Effects on the EEG:

Table 9: Drug Effects on EEG

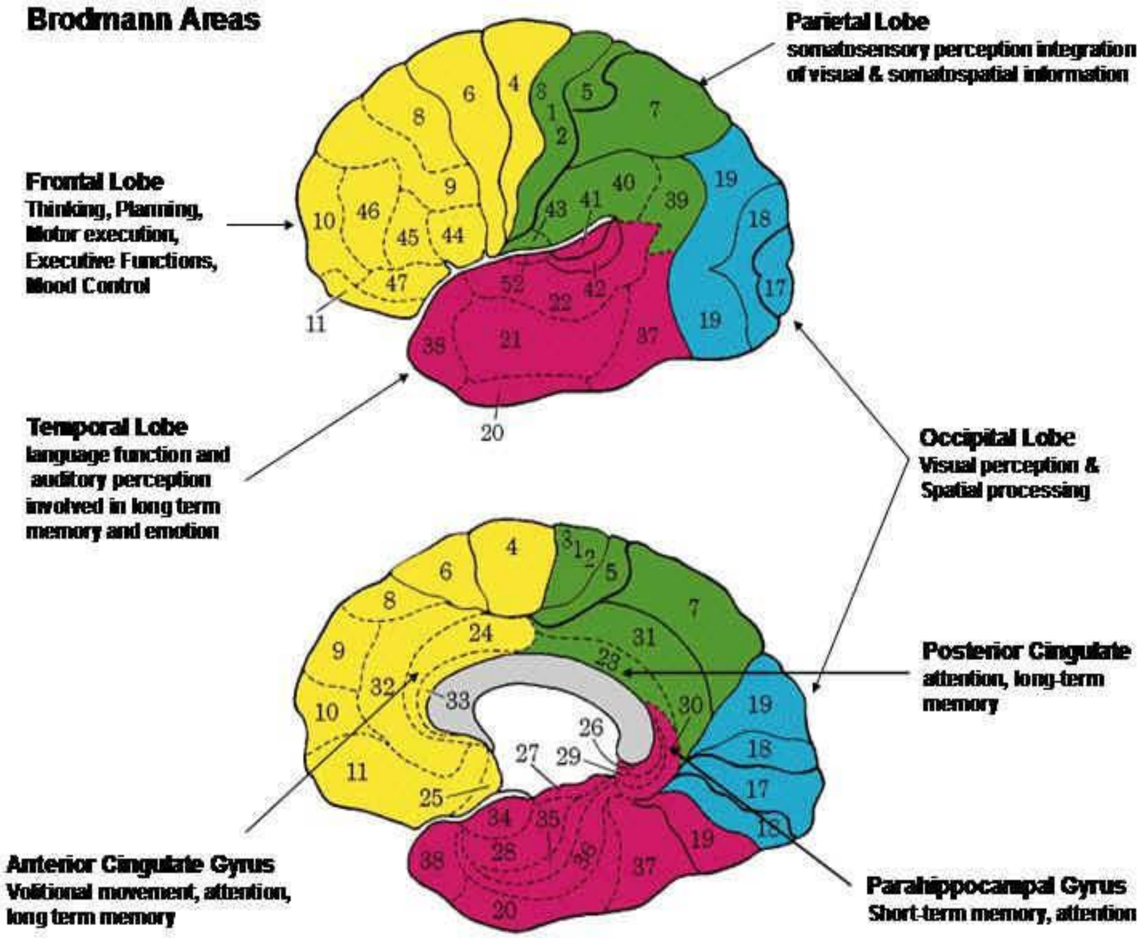
Family	Drugs	Purpose	EEG Impact
Neuroleptics	Haldol, Prolixin, Thorazine, Mellaril	Sedative	Increase delta, theta and beta above 20 Hz and decrease alpha and beta below 20 Hz.
Neuroleptics	Seroquel, Risperdal, Geodone	Non-sedative and antipsychotic medications	Decrease alpha and increase beta in general.
Anxiolytics	Valium, Halcion, Librium, Dalmane	Anxiety relief	Decrease alpha and increase beta, especially 13-20 Hz beta
Benzodiazepines	Valium, Xanax, and Ativan	Anxiety, panic relief	Decrease alpha and increase 20-30 Hz beta
SSRIs	Prozac, Paxil, and Zoloft	a class of antidepressants used in the treatment of depression, anxiety disorders, and some personality disorders.	Decrease in frontal alpha and a mild increase in 18-25 Hz beta.
MAO Inhibitors	Marplan, Parnate, Eldepryl	Antidepressant	Tendency to increase 20-30 Hz beta while decreasing all other frequencies
Tricyclic antidepressants	Imipramine and Amitriptyline	Useful in depressed patients with insomnia, restlessness, and nervousness	Increase delta and theta while decreasing alpha; increase beta 25 Hz and up band
Antipsychotics	Lithium	Used for the treatment of manic/depressive (bipolar) and depressive disorders	Increases theta, mildly decreases alpha and increases beta
Amphetamines	Adderall, Vyvanse, and Dexedrine.	a group of drugs that act by increasing levels of norepinephrine, serotonin, and dopamine in the brain	Decrease slow-wave activity and increase beta in the 12-26 Hz range
Marijuana		Recreational	Increases frontal low frequency alpha; affects EEG for three days
Opiates	Opium, hydromorphone, oxymorphone, heroin, morphine, oxycodone, Talwin, codeine, methadone, meperdine, hydrocodone, Vicodin	Pain relief	Generate high amplitude slow alpha in the 8 Hz range
Barbiturates	Brevital, thiamylal (Surital), thiopental (Pentothal), amobarbital, Amytal, pentobarbital, Nembutal, secobarbital, Seconal, Tuinal, Phenobarbital, Luminal, mephobarbital, Mebaral	Produce a wide spectrum of central nervous system depression, from mild sedation to coma, and have been used as sedatives, hypnotics, anesthetics, and anticonvulsants	Increase beta at 25-35 Hz amplitude
Caffeine		Increases alertness	Increases beta and decreases slower waves

Brodmann Areas:

Table 3: Brodmann Areas and Localization of Function

SITE	BRODMANN AREA	FUNCTION
Fpz	10, 11, 32	Emotional inhibition, oversensitive, impulsive Motivation & attention
Fp1	10, 11, 46	Cognitive emotional valence - lateral orbital frontal Irritability, intrusive, depression Social awareness - approach behaviors
Fp2	10, 11, 46	Emotional inhibition - lateral orbital frontal Impulsivity, tactlessness, mania Social awareness - avoidance behaviors
F7	45, 47, 46	Working memory - visual & auditory Divided & selective attention - filtering Broca's area - semantic short-term buffer (word retrieval)
F8	45, 47, 46	Prosody Working memory - spatial & visual, gestalt Facial emotional processing Sustained attention
F3	8, 9, 46	Short-term memory - verbal episodic retrieval Facial recognition, object processing Planning & problem solving - Wisconsin card sort (rigidity)
F4	8, 9, 46	Short-term memory - spatial/object retrieval Vigilance area - selective & sustained attentional area
Fz	8, 6, 9	Personality changes Intention & motivation - poverty of speech, apathy Possible anterior cingulate - internal vs. external attention Basal ganglia output
C3	3, 1, 4	Sensory & motor functions
C4	3, 1, 4	Sensory & motor functions
Cz	6, 4, 3	Sensory & motor functions
T3	42, 22, 21	Language comprehension - verbal understanding Wernicke's area - inner voice Long-term memory - declarative & episodic processing Event sequencing - visualization Amygdala/hippocampal area
T4	42, 22 ,21	Personality - emotional tonality (anger, sadness) Categorization & organization Visualization and auditory cortex
T5	39, 37, 19	Meaning construction - angular gyrus Acalcula Short-term memory
T6	39, 37, 19	Facial recognition - emotional content, amygdalic connection
P3	7, 40, 19	Digit span problems, information organization problems Self-boundaries excessive thinking
P4	7, 40, 19	Visual processing - spatial sketch pad, vigilance Personality - excessive self-concern, victim mentality Agnosia, apraxia, context boundaries, rumination
Pz	7, 5, 19	Attentional shifting- perseverance Self-awareness, orientation association area Agnosia, apraxia
O1, O2	18, 19, 17	Visual processing, procedural memory, dreaming
Oz	18, 17, 19	Visual processing, hallucinations

 New Mind Neurofeedback Center

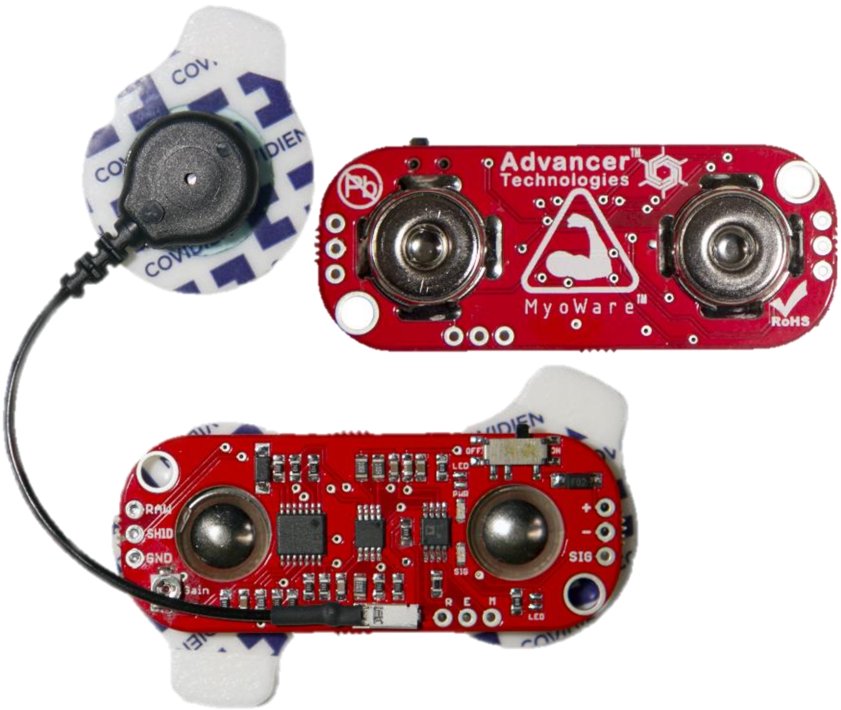

Brodmann Areas
Parietal Lobe
somatosensory perception integration of visual & somatospatial information
Frontal Lobe
Thinking, Planning, Motor execution, Executive Functions, Mood Control
Temporal Lobe
language function and auditory perception involved in long term memory and emotion
Occipital Lobe
Visual perception & Spatial processing
Posterior Cingulate
attention, long-term memory
Anterior Cingulate Gyrus
Volitional movement, attention, long term memory
Parahippocampal Gyrus
Short-term memory, attention

A.2 EMG Data Sheet

3-lead Muscle / Electromyography Sensor for Microcontroller Applications

MyoWare™ Muscle Sensor (AT-04-001) DATASHEET

FEATURES
- *NEW* - Wearable Design
- *NEW* - Single Supply
  - +2.9V to +5.7V
  - Polarity reversal protection
- *NEW* - Two Output Modes
  - EMG Envelope
  - Raw EMG
- *NEW* - Expandable via Shields
- *NEW* - LED Indicators
- Specially Designed For Microcontrollers
- Adjustable Gain

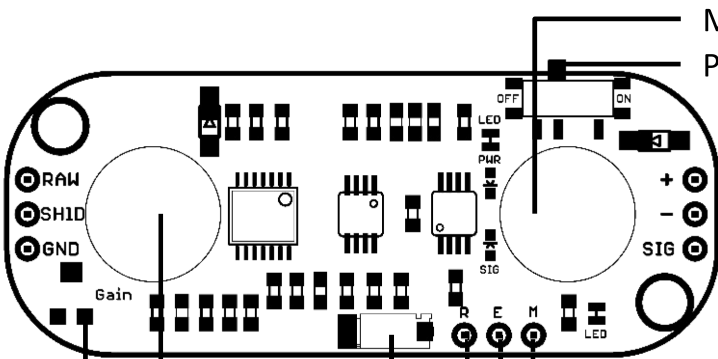


APPLICATIONS
- Video games
- Robotics
- Medical Devices
- Wearable/Mobile Electronics
- Prosthetics/Orthotics

What is electromyography?

Measuring muscle activation via electric potential, referred to as electromyography (EMG), has traditionally been used for medical research and diagnosis of neuromuscular disorders. However, with the advent of ever shrinking yet more powerful microcontrollers and integrated circuits, EMG circuits and sensors have found their way into prosthetics, robotics and other control systems.

Sensor Layout



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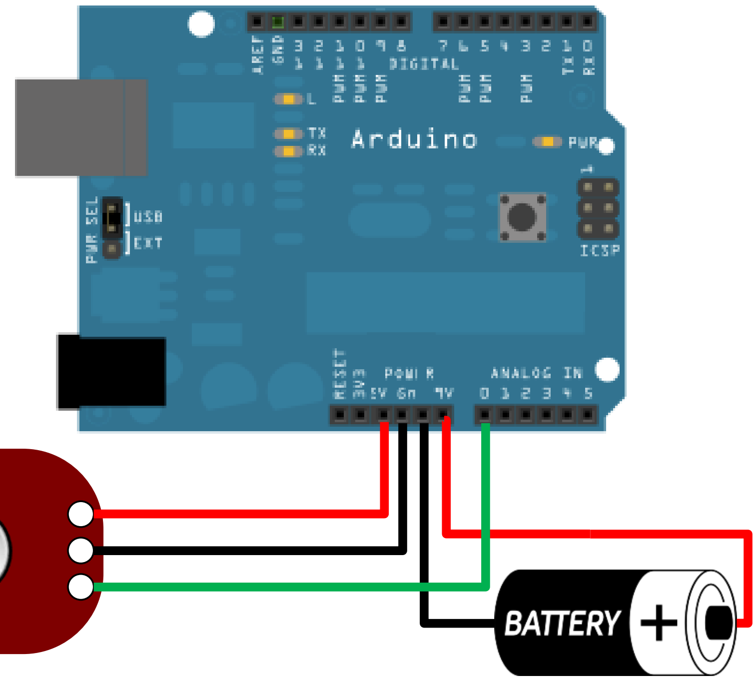
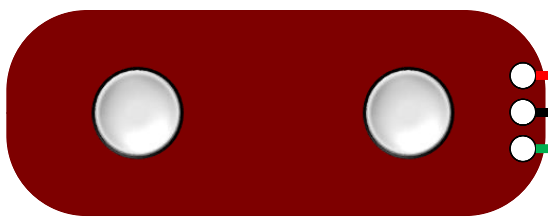
Setup Configurations *(Arduino is shown but MyoWare is compatible with most development boards)*

a) Battery powered with isolation via no direct external connections

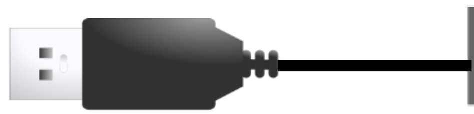
RECOMMENDED

Note: Since no component is connected to electrical grid, further isolation is not required. It is also acceptable to power the MCU with a battery via the USB or barrel ports.

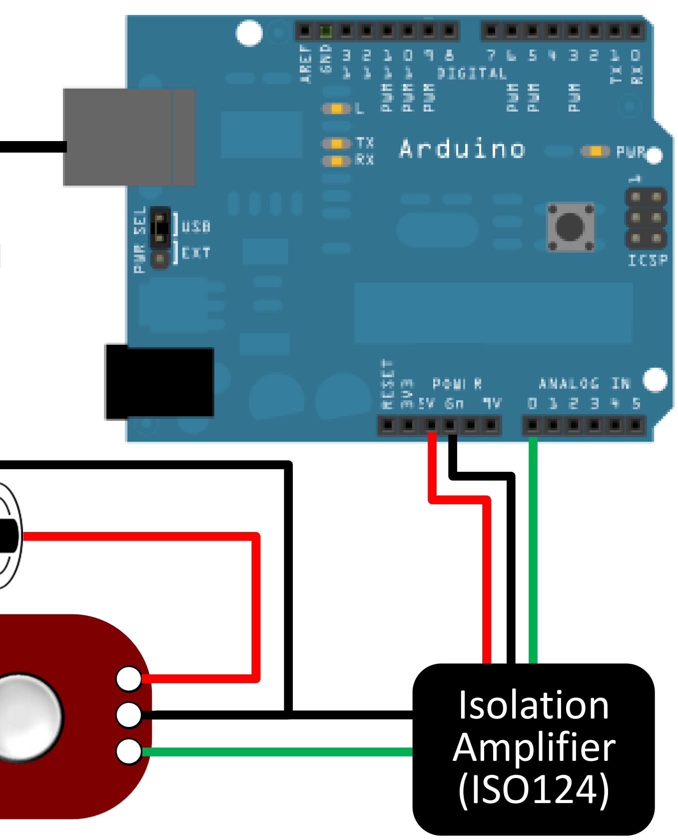


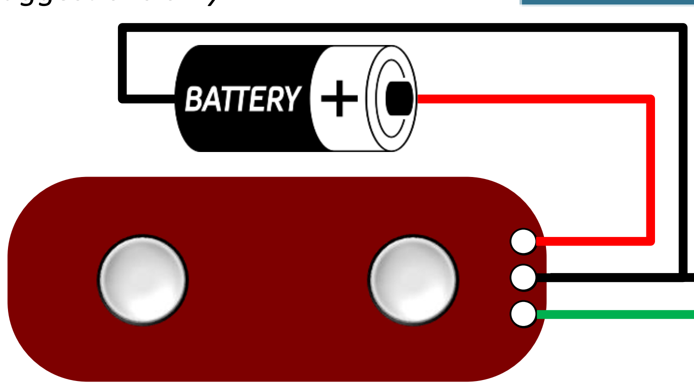


b) Battery powered sensor, Grid powered MCU with output isolation



Note: Isolation amplifier and battery provide isolation between user and electrical grid. *IC models are suggestions only.*





(Note: Arduino and batteries not included. Arduino setup is only an example; sensor will work with numerous other devices.)

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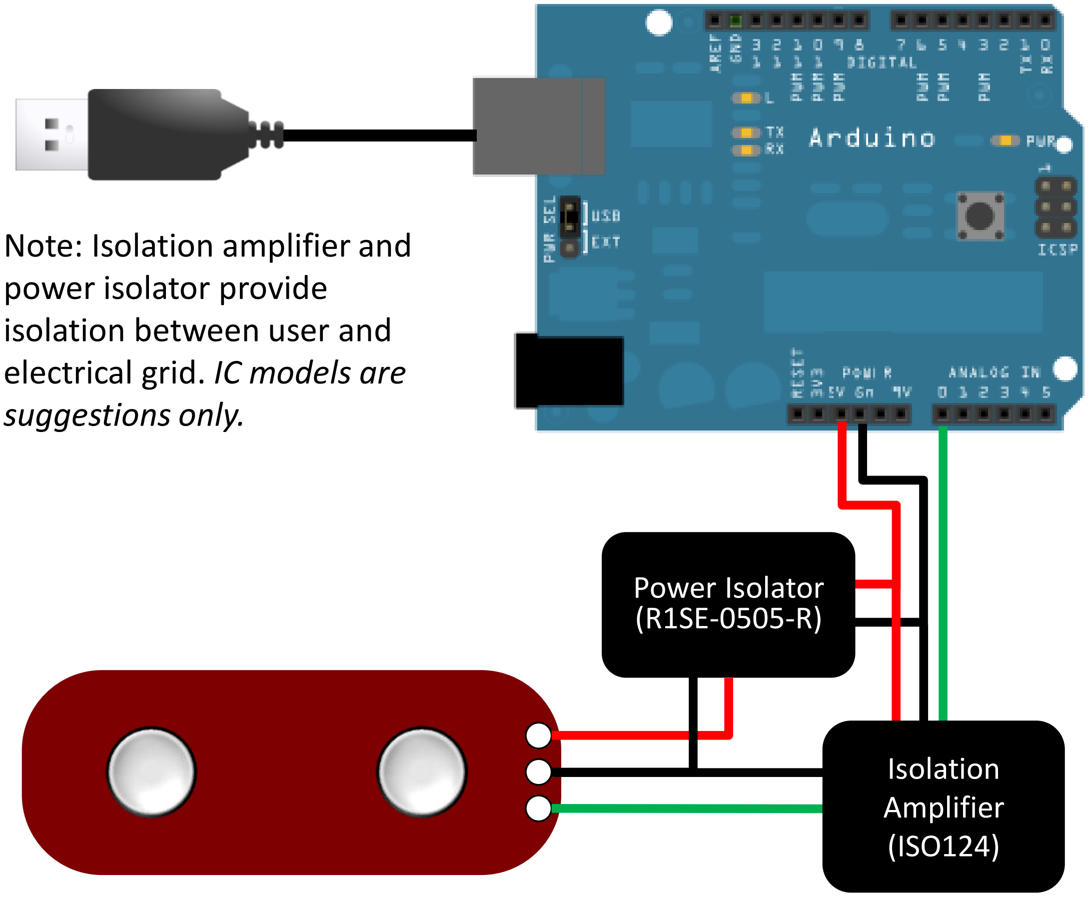
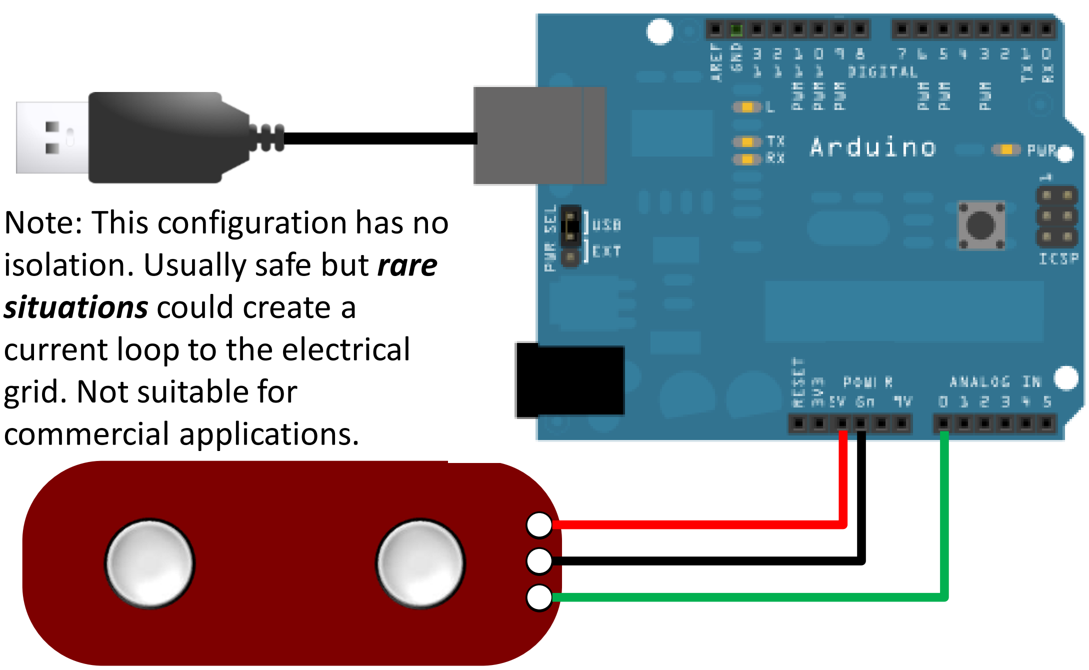
Setup Configurations (cont'd)

c) Grid powered with power and output isolation



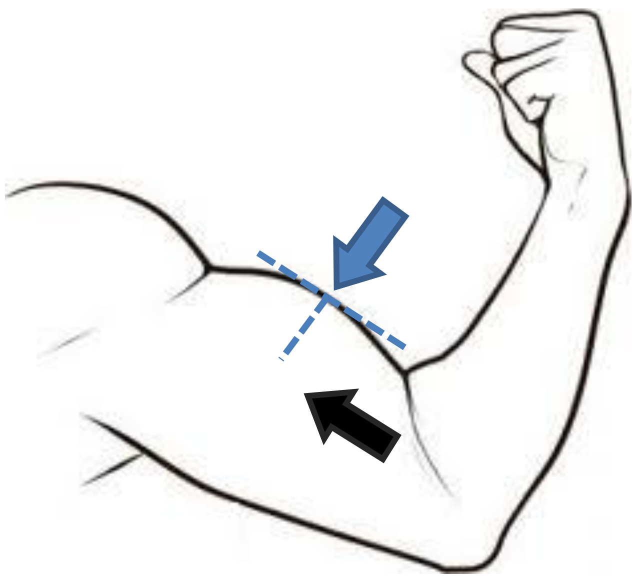
Note: Isolation amplifier and power isolator provide isolation between user and electrical grid. *IC models are suggestions only.*

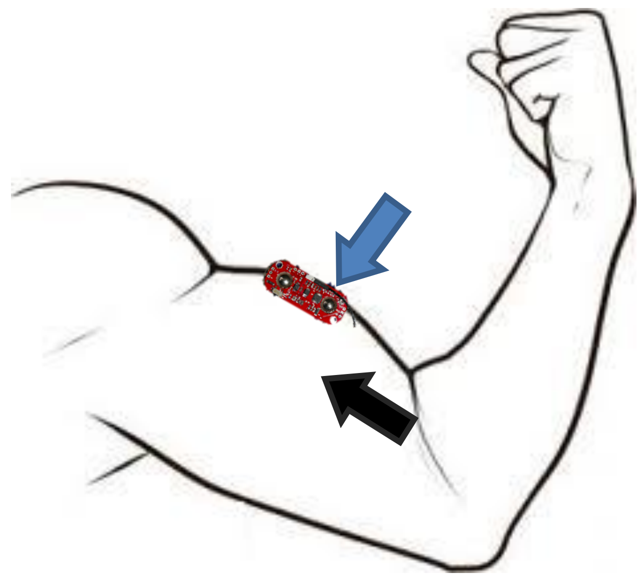
d) Grid powered. ***<u>Warning: No isolation.</u>***



Note: This configuration has no isolation. Usually safe but ***rare situations*** could create a current loop to the electrical grid. Not suitable for commercial applications.

Setup Instructions



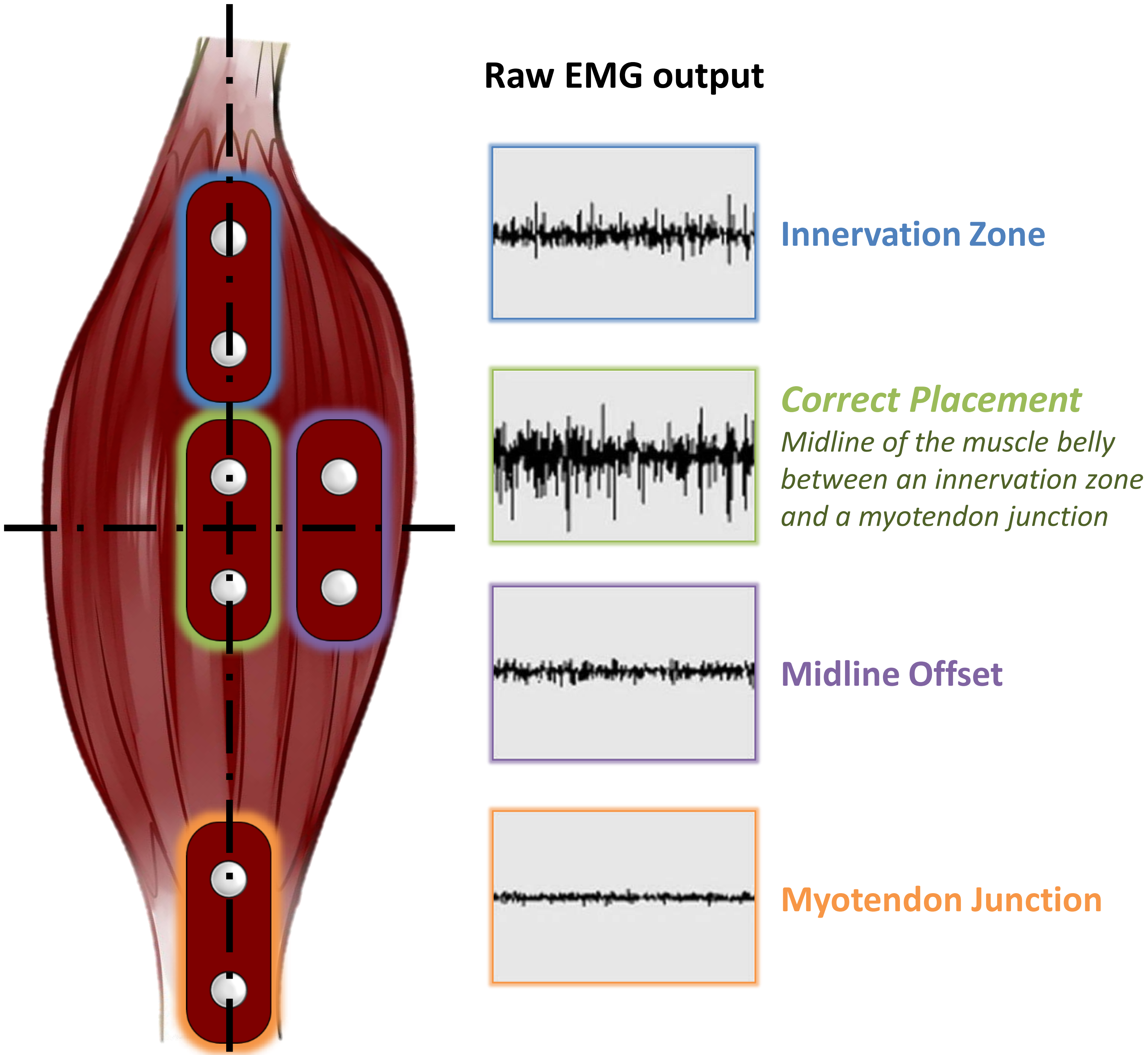


Note: Not To Scale

Example Sensor Location for Bicep

1) Thoroughly clean the intended area with soap to remove dirt and oil
2) Snap electrodes to the sensor's snap connectors
   (Note: While you can snap the sensor to the electrodes after they've been placed on the muscle, we do not recommend doing so due to the possibility of excessive force being applied and bruising the skin.)
3) Place the sensor on the desired muscle
   a. After determining which muscle group you want to target (e.g. bicep, forearm, calf), clean the skin thoroughly
   b. Place the sensor so one of the connected electrodes is in the middle of the muscle body. The other electrode should line up in the direction of the muscle length
   c. Peel off the backs of the electrodes to expose the adhesive and apply them to the skin
   d. Place the reference electrode on a bony or nonadjacent muscular part of your body near the targeted muscle
4) Connect to a development board (e.g. Arduino, RaspberryPi), microcontroller, or ADC
   a. See configurations previously shown

Why is electrode placement important?



Position and orientation of the muscle sensor electrodes has a vast effect on the strength of the signal. The electrodes should be place in the middle of the muscle body and should be aligned with the orientation of the muscle fibers. Placing the sensor in other locations will reduce the strength and quality of the sensor's signal due to a reduction of the number of motor units measured and interference attributed to crosstalk.

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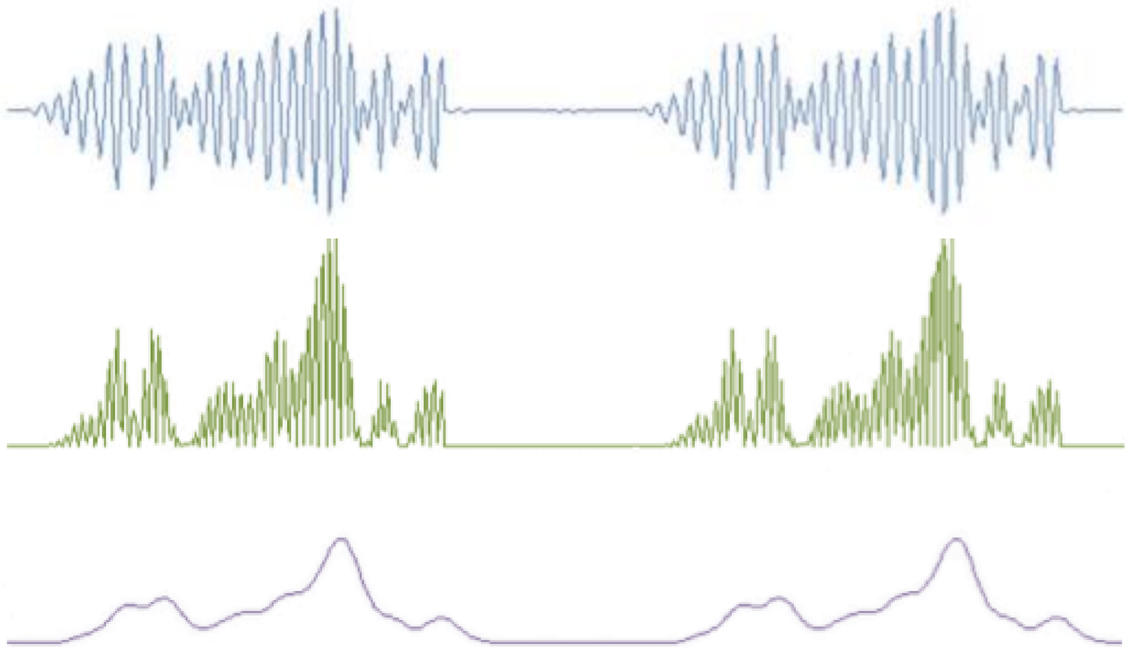
RAW EMG vs EMG Envelope

Our Muscle Sensors are designed to be used directly with a microcontroller. Therefore, our sensors primary output is not a RAW EMG signal but rather an amplified, rectified, and integrated signal (AKA the EMG's envelope) that will work well with a microcontroller's analog-to-digital converter (ADC). This difference is illustrated below using a representative EMG signal. *Note: Actual sensor output not shown.*

RAW EMG Signal

Rectified EMG Signal

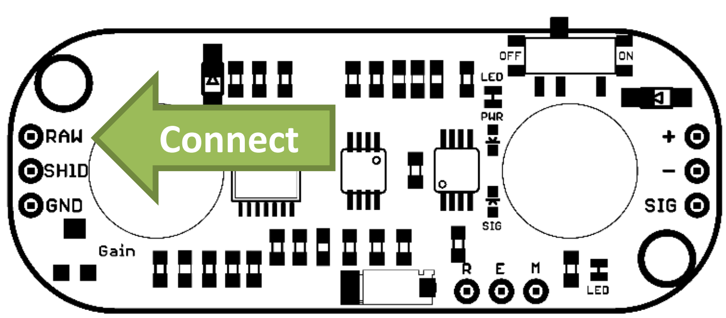
Rectified & Integrated EMG Signal



Reconfigure for Raw EMG Output

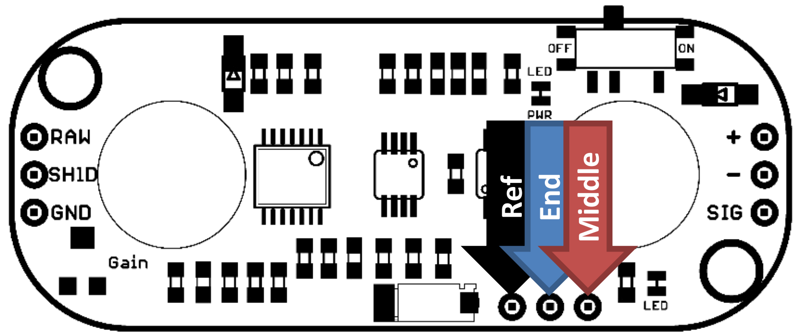
This new version has the ability to output an amplified raw EMG signal.
To output the raw EMG signal, simply connect the raw EMG signal pin to your measuring device instead of the SIG pin.

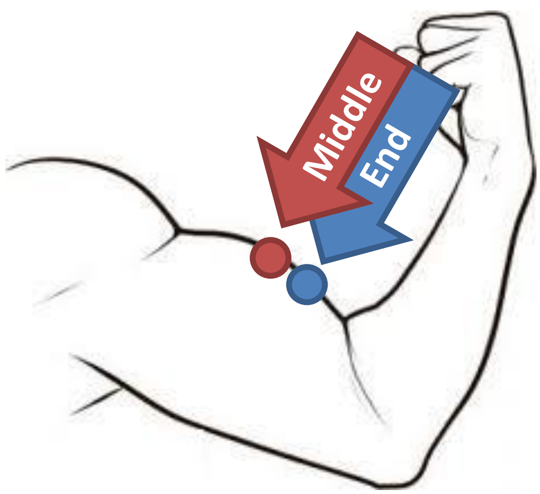
Note: This output is centered about an offset voltage of +Vs/2, see above. It is important to ensure +Vs is the max voltage of the MCU's analog to digital converter. This will assure that you completely see both positive and negative portions of the waveform.



Connecting external electrode cables

This new version has embedded electrode snaps right on the sensor board itself, replacing the need for a cable. However, if the on board snaps do not fit a user's specific application, an external cable can be connected to the board through three through hole pads shown above.





Middle
Connect this pad to the cable leading to an electrode placed in the middle of the muscle body.

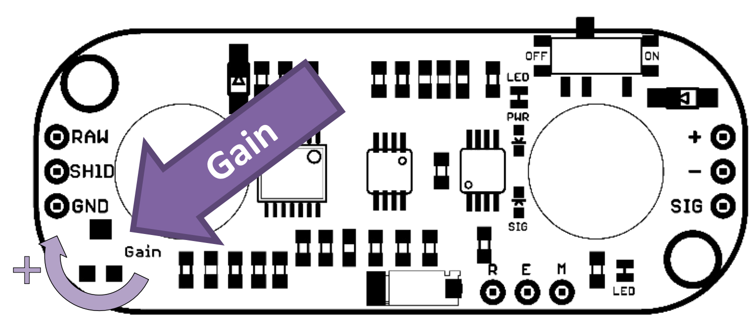
End
Connect this to the cable leading to an electrode placed adjacent to the middle electrode towards the end of the muscle body.

Ref
Connect this to the reference electrode. The reference electrode should be placed on an separate section of the body, such as the bony portion of the elbow or a nonadjacent muscle

Adjusting the gain

We recommend for users to get their sensor setup working reliably prior to adjusting the gain. The default gain setting should be appropriate for most applications.
To adjust the gain, locate the gain potentiometer in the lower left corner of the sensor (marked as "GAIN"). Using a Phillips screwdriver, turn the potentiometer counterclockwise to increase the output gain; turn the potentiometer clockwise to reduce the gain.

Note: In order to reduce the required voltage for the sensor, the redesign switch out a JFET amplifier for a CMOS amplifier. However CMOS amplifiers tend to have slower recovery times when saturated. Therefore, we advise users to adjust the gain such that the output signal will not saturate the amplifier.



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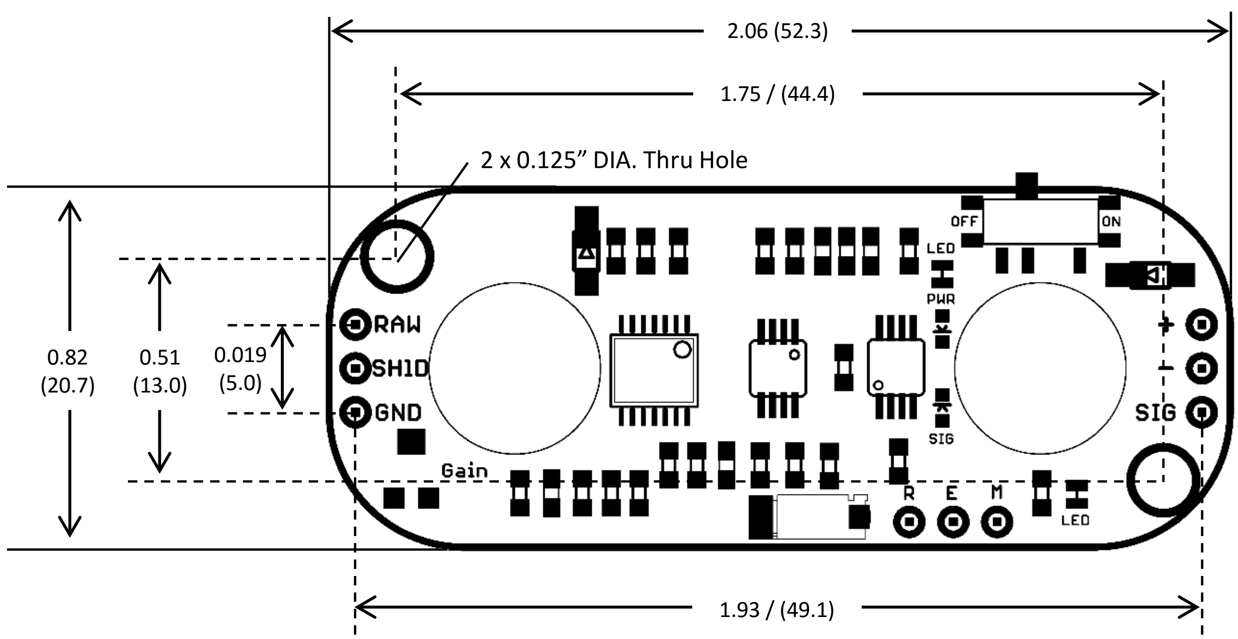
Electrical Specifications

Parameter	Min	TYP	Max
Supply Voltage	+2.9V	+3.3V or +5V	+5.7V
Adjustable Gain Potentiometer	0.01 Ω	50 kΩ	100 kΩ
Output Signal Voltage EMG Envelope Raw EMG (centered about +Vs/2)	 0V 0V	 -- --	 +Vs +Vs
Input Impedance	--	110 GΩ	--
Supply Current	--	9 mA	14 mA
Common Mode Rejection Ratio (CMRR)	--	110	--
Input Bias	--	1 pA	--

Dimensions



A.3 EMG and Breath Rate Arduino Code

breathEMGarduino | Arduino 1.6.8

File Edit Sketch Tools Help

breathEMGarduino

```
//Smoothing Function for Breath Rate: inhale (1) vs exhale (0)
//EMG Incremental Thresholds

//---BREATH RATE GLOBAL VARIABLES --------------------------------------------------------------------------------

const int numReadingsBreath = 13;                  // number of samples to average over. Magnitude inversley correlated to processing speed.
float inputPinBreath = A1;

float readingsBreath[numReadingsBreath];        // the readings from the analog input
int readIndexBreath = 0;                        // the index of the current reading
float totalBreath = 0;                          // the running total
float averageBreath = 0;                        // the average
float oldAverageBreath = 0;
float slopeBreath = 0;
int  breathOutput = 0;


//---EMG GLOBAL VARIABLES--------------------------------------------------------------------------------------
const int numReadingsEMG = 10;                 //number of samples to average over. Magnitude inversley correlated to processing speed.
float inputPinEMG = A0;

float readingsEMG[10];                         // the readings from the analog input
int readIndexEMG= 0;                           // the index of the current reading
float totalEMG = 0;                            // the running total
float averageEMG = 0;                          // the average of the signal

float normalizedEMG = 0;                      //normalization of EMG at rest
float readingEMG = 0;                         //current reading
int flexTimeEMG = 0;
int ratioEMG = 0;                             //ratio between current reading and normalized rest
float maxEMG = 0;                             //max reading of flexion
int maxRatioEMG = 0;
int percentTotalEMG = 0;
//----------------------------------------------------------------------------------------------------------

void setup() {
  Serial.begin(115200);              //baud rate
                                     // initialize all the readings to 0:
  setup_emg();
  setup_breath();
}

void setup_emg()
{
  for (int thisReadingEMG = 0; thisReadingEMG < numReadingsEMG; thisReadingEMG++) {  // initialize all the readings to 0:
    readingsEMG[thisReadingEMG] = 0;
  }
  Serial.println("P---Relax Arm---");
  delay(200); // delay 0.2 second

  for (int i=0; i <= 50; i++) {                   // get average of arm at rest to normalize for thresholding
    readingEMG = analogRead(inputPinEMG);
    normalizedEMG = normalizedEMG + readingEMG;
    delay(30);
  }
  normalizedEMG = normalizedEMG/50;                // average of rest period's 50 data points
  //Serial.print("rest value: ");
  //Serial.println(normalizedEMG);
  Serial.println("P---EMG Normalized---");
  Serial.println("P---Flex Now ---");              //get maximum reading from flexion for comparison

  flexTimeEMG = millis();                          //calibrate: user flexes an we get maximum reading of a flexion
  while(millis() < flexTimeEMG+2000){
    readingEMG = analogRead(inputPinEMG);
    if (readingEMG > maxEMG){
      maxEMG = readingEMG;
    }
  }
  //Serial.print("Max EMG Value: ");
  //Serial.println(maxEMG);
  maxRatioEMG = maxEMG/normalizedEMG;
  //Serial.print("Max EMG Ratio: ");
  //Serial.println(maxRatioEMG);
  Serial.println("Intialization complete");
  delay(1000);
}

void setup_breath(){
  for (int thisReadingBreath = 0; thisReadingBreath < numReadingsBreath; thisReadingBreath++) {
```

```
    readingsBreath[thisReadingBreath] = 0;
  }

}

void loop() {
  loop_emg();
  loop_breath();
  delay(40);      // delay in between reads for stability. decrease value to increase speed, but may increase noise.
}

void loop_emg(){
  totalEMG = totalEMG - readingsEMG[readIndexEMG];            // SMOOTHING FUNCTION -- subtract the last reading:
  readingsEMG[readIndexEMG] = analogRead(inputPinEMG);       // read from the sensor:
  totalEMG = totalEMG + readingsEMG[readIndexEMG];          // add the reading to the total:
  readIndexEMG = readIndexEMG + 1;                         // advance to the next position in the array:
  if (readIndexEMG >= numReadingsEMG) {                   // if we're at the end of the array...
    readIndexEMG = 0;                                    // ...wrap around to the beginning:
  }
  averageEMG = totalEMG / numReadingsEMG;                  // calculate the average:
  ratioEMG = averageEMG/ normalizedEMG;                   // ratio between current reading and rest
  percentTotalEMG = ratioEMG*100/maxRatioEMG;           // percent of current flex/maximum flex in intialization


  Serial.print("E");                               //UNCOMMENT FOR WRITING RAW DATA WITH PROCESSING CODE
  //Serial.println(averageEMG);                   // for troubleshooting/plotting
  //Serial.println(ratioEMG);                    // for troubleshooting/plotting
  Serial.println(percentTotalEMG);
}

void loop_breath(){
  totalBreath = totalBreath - readingsBreath[readIndexBreath];        // subtract the last reading:
  readingsBreath[readIndexBreath] = analogRead(inputPinBreath);      // read from the sensor:
  totalBreath = totalBreath + readingsBreath[readIndexBreath];      // add the reading to the total:
  readIndexBreath = readIndexBreath + 1;                           // advance to the next position in the array:

  if (readIndexBreath>= numReadingsBreath) {                     // if we're at the end of the array...
    readIndexBreath = 0;                                        // ...wrap around to the beginning:
  }

  averageBreath = totalBreath / numReadingsBreath;            // calculate the average:
  slopeBreath = averageBreath-oldAverageBreath;

  //Serial.println(averageBreath);                         // get breath rate curve for troubleshooting/plotting

  if (slopeBreath >= 0.1) {                              // boolean of inhale (1)
     breathOutput = 1;                                  //if slope is between -0.1 & 0.1 (high noise) just keep old value
  }
  else if (slopeBreath<=-0.1){                             // boolean of exhale (0)
      breathOutput = 0;
  }
  else {
    breathOutput = breathOutput;
  }
  Serial.print("B");                      //UNCOMMENT FOR WRITING RAW DATA WITH PROCESSING CODE
  Serial.println(breathOutput);
  oldAverageBreath = averageBreath;
}

/* Using code from:

  Created 22 April 2007
  By David A. Mellis  <dam@mellis.org>
  modified 9 Apr 2012
  by Tom Igoe
  http://www.arduino.cc/en/Tutorial/Smoothing
*/
```

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Boards shall have the opportunity to discuss proposed changes prior to final action by the Board of Directors, and An affirmative vote of two-thirds of the votes of the members of the Board of Directors present at the time of the vote, provided a quorum is present, shall be required for changes to be made.