Optimal Design Report
Auditory and Visual Stimuli System for Fast Eye Movement Analysis

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1. Optimal Design Project

1.1 Introduction

In the United States alone, around one million people suffer at least one concussion every year. In today’s society, many people are at risk for concussions including people who partake in popular contact sports such as football and hockey, as well as active members of the military. If ignored or treated improperly, concussions can lead to very serious long term traumatic brain injuries and even death.

The client, Dr. John Enderle has been researching rapid eye movements and their respective neuronal activities for the past thirty years. His research has led to the belief that there is a way to determine whether or not a person has suffered mild traumatic brain injury based on their results from a visual/auditory stimuli combination eye movement test. Dr. Enderle believes that he will be able to accurately diagnose concussions based on a patient’s eye movements in response to these stimuli. Our goal is to create a device that is able to record a subject’s rapid eye movements in response to a combination of visual and auditory stimuli that is activated simultaneously at various locations in the subject’s range of vision. The device must also be able to display the recorded eye movements in a user friendly way which allows for further data analysis and comparisons.

The main component of our device will be an arched black board that will be mounted on a wall at a height that is at the subject’s eye level. The black board will have seventy seven red LED lights arranged evenly in a series of rows and columns. We chose red LED lights for many reasons. Due to the LED lights being red, they stand out very clearly because of the contrast with the black board. The LED lights are also small and don’t require a large amount of power to be activated. We also chose LED lights because microcontrollers can be easily programmed to activate LEDs and we have a background in such programming.

The black board will also have seventy seven speakers implemented into it at each LED location. The speakers will be small and inexpensive circular speakers. Due to the amount of speakers needed, it is essential that the speakers are inexpensive. The speakers will be able to be activated simultaneously with their corresponding LEDs. Small speakers also do not require a large amount of power to be activated which is beneficial.

The activation of the speakers and LED lights will be controlled by an Arduino brand microcontroller. An Arduino Mega 2560 will be used because it 54 digital input/output pins and due to the large number of LEDs and speakers, it is very beneficial to have as many digital input/output pins as possible.

Due to the large amount of auditory and visual stimuli sources that need to be controlled by the Arduino, we will be using shift registers in order to give the Arduino the ability to control the activation of the large number of sources. The shift registers we will be using are the Goldstar 74HC164s. Shift registers are essential in our design because they reduce wire count reducing the risk of wires coming loose and because they allow each pin of the Arduino to be
able to handle more inputs. Shift registers are also beneficial because they take some load off of the Arduino because they can store data.

Our device will use an electrooculography (EOG) electrode setup to record the rapid eye movements. The electrodes will be placed using standard EOG electrode placement. The EOG signal will be inputted into a LabView program which will display the recorded eye movements in a user friendly manner that will allow for data analysis.

Figure 1: Standard Electrode Placement for EOG

The Arduino will be programmed so that the LEDs and speakers are activated in a manner that appears random to the subject being tested. Figure 2 shows a flow chart of the series of events that occur in the auditory and visual stimuli system.
Figure 2: Block Diagram for Auditory/Visual Stimuli Test

- Computer Powers Arduino Microcontroller
- Power Transferred to Shift Registers
- One Set of LEDs and Speakers is Activated
- EOG Electrodes Record Eye Movements
- LabView Displays Recorded Eye Movements
1.2 Subunits

Our auditory and visual stimuli system can be broken down into several subunits which will be explained in detail below.

1.2.1 Arched Black Board

The main component of our auditory and visual stimuli system for rapid eye movement analysis is a customized arched black board which contains seventy seven LEDs and seventy seven speakers. The black board is arched so that the subject is able to respond to stimuli in more than just one plane. The arch of the board allows for eye movements to be tested at as many angles as possible and allows for the examination of the subject’s response to stimuli in three dimensions.

1.2.2 Small Red LED Lights

The LEDs will be arranged in a series of columns and rows that are evenly spaced out. The LEDs will be red LED lights which make it very easy for the subject to locate them on the board due to the contrast between the red lights and the black board behind them. This is essential to the success of our device because the subject needs to be able to react to the visual stimuli as easily as possible and the contrasting colors will make it easy for the subject to focus on the LEDs. LEDs are also beneficial to use as the visual stimuli source because they do not require a large amount of power to be activated. LED lights are also cheap and dependable making them ideal for our system. LED lights have an estimated operational life of 100,000 hours making them far superior to alternative types of lights such as an incandescent bulb which has an operational life of approximately 5,000 hours. This long operational life is beneficial to our design because it will lead to our device requiring less maintenance and will allow the device to be able to test many more patients before the need for replacement lights.

Figure 3: Small Red LED Light
Another benefit of using LED lights is that they are easily programmable through an Arduino microcontroller. Our group has some experience in programming LEDs through microcontrollers and this was another factor in our decision to use LEDs. The background we have in programming LEDs gives us an advantage in building this device and will allow us to more easily build a successful device. The LEDs will be mounted on the plane of the black board so that they are easily visible to the subject being tested.

1.2.3 Small Inexpensive Speakers

In order to generate auditory stimuli for the purpose of testing the patient’s eye movement response to auditory stimuli, we will implement seventy seven small and inexpensive speakers into the device. Due to the large amount of speakers needed for our device, it is very important that the speakers are relatively cheap so that we will stay under budget. Small speakers are ideal because they do not require a lot of power in order to be activated.

We chose to use seventy seven Piezo 70S110 speakers for our design. These speakers are ideal for our device because they are only $0.50 each and can be activated using an Arduino microcontroller. These speakers are also advantageous for our device because they come with wiring which saves us from having to purchase extra wire for each speaker. Although these speakers are small and inexpensive, they are able to create a clear sound when powered by an Arduino which is vital to the success of our device because the subject needs to be able to clearly hear the sound when undergoing examination. If the sound is not clear, the subject’s reaction to the auditory stimuli will not be to their greatest ability and therefore the recorded eye movements will not be sufficient in diagnosing possible mild traumatic brain injury.
The seventy seven Piezo 70S110 speakers will be implemented at the same locations as the seventy seven LEDs. The speakers will need to be as close to the same exact locations as the LEDs as possible. This is necessary because in order to test the eye movement response to auditory and visual stimuli, the two types of stimuli need to be coming from the same location in order to make the test accurate. The device will record the angle of eye movement as part of the examination and if the speakers and LEDs are not at the same locations, the recorded eye movements will be inaccurate because the two stimuli sources will not be at the exact same angle.

In order for the speakers and LEDs to be at the same location, we will need to modify the arched black board. We will cut around each LED so that each speaker can be implemented directly behind each LED. The cut we will make is shown in Figure 5.

![Figure 5: Cut Made Around Each LED Light](image)

This cut around each LED will allow us to implement speakers directly behind the LEDs and will allow for the device to generate auditory and visual stimuli from the same locations. This cut will be duplicated around all seventy seven LEDs. The cut will be circular to match the shape of the Piezo speaker and the cute will be large enough so that no part of the speaker is blocked by the board. The two areas attached to the LED will be cut as thin as possible while still holding the LED securely. This is beneficial to our design because that will make it so that as little of the speaker is covered as possible. This cut design will aid in the production of a clear
sound by each speaker because very little of each speaker will be covered. This cut will also make it so that the patient can easily identify the location of the auditory stimuli when each speaker is activated. If this cut was not made, the speakers would be covered by the black board and the subject would have a very difficult time trying to identifying the location of the sound and their eye movement response would not be ideal.

Once the cut is made around each LED and the speakers and LEDs are wired, we will need to test the functionality of the LEDs and speakers together. We will hook up the LED and speakers to a Protoboard and power the circuit using a 5 volt power source to see if the LEDs and speakers could be activated simultaneously using our setup. We will need to test each set of LEDs and speakers this way to assure that all sets of speakers and LEDs function.

1.2.4 Protective Foam Layer for Speakers

In order for the speakers to function at the most optimal level, they will need to be protected. Dust and other particles can reach speakers if they are unprotected and this will cause the speakers to perform at a subpar level. As previously mentioned, the speakers must be able to produce a clear sound so that the subject can respond to the auditory stimuli to their full ability. If the sound is deterred in any way, the subject’s eye movement in response to the auditory stimuli will not be sufficient for an accurate diagnosis.

Due to the cut being made around each LED, the speakers will need a layer of protection over them to keep them from being exposed. We have decided to cover the hole in front of each speaker with a layer of thin black foam that is traditionally used to cover ear buds.

Figure 6: Think Black Foam Ear Bud Covers
This layer of thin black foam is beneficial in several ways. The first benefit of using this layer of thin black foam is that it serves as a layer of protection. This black foam has been used in the past in covering ear buds and has proven to serve as a sufficient protective layer for speakers. Another benefit of using this foam is that it is very thin and sound is able to move through it without being obstructed. This is a very desirable quality in the protective layer because it allows the speakers to still produce a clear sound that will allow the subject to easily identify the location of the auditory stimuli during testing.

The black foam layer is also needed so that the hole that is cut is covered up and the wires and circuit parts are not visible to the subject being tested. If the wires and circuit parts were visible to the subject being tested, the subject would be distracted from focusing on the LED lights and their eye movement response to the visual stimuli may not be an accurate representation of their response to the LED lights.

The black foam layer also is an advantageous way to cover the holes that are cut because they are black will not serve as a distraction to the patient. The black board will be completely covered by the black foam and holes will be cut into the foam at each LED location so that the LEDs will still be completely visible. The fact that the foam is black is also beneficial because the black contrasts with the color of the red LEDs and allows for the LEDs to stand out as much as possible. This is vital to the success of our device because the subject needs to be able to clearly see all of the visual stimuli sources so that their eye movement response is produced to their fullest ability and without distraction.

![Figure 7: Black Foam Cover over Holes Cut Around Each LED](image-url)
1.2.5 Arduino Mega 2560 Microcontroller

Per request of our client, our device must be to activate the LEDs and speakers at the same location simultaneously. The device must also be able to activate each set of LEDs and speakers in a manner in which their activation appears random to the subject being tested. This randomized activation is vital to the device’s success because the subject cannot know the order of which sources of stimuli will be activated. If the patient were to know the order of stimuli activation before testing, the test would be flawed and their eye movement measurements would not be a true measurement of their ability to respond to the stimuli. We chose to use an Arduino Mega 2560 Microcontroller to control the activation of the LEDs and speakers. The Arduino Mega 2560 has 54 digital input/output pins which is more than any other Arduino model. The large number of digital input/output pins is beneficial to our device because we need to be able to control seventy seven LEDs and seventy seven speakers. The Arduino is also beneficial because it can be connected directly to a computer through a USB cord so that we can directly program the Arduino from the computer.

Figure 8: Arduino Mega 2560

Another benefit of using an Arduino is that the Arduino can be programmed using C programming language. Our group has some background in using C programming language
which is beneficial because it will allow us to use prior knowledge to program the Arduino which will make it easier than having to learn a new programming language.

1.2.6 Goldstar 74HC164 Shift Registers

Due to the large amount of speakers and LEDs needed in our device, we will need to increase the capabilities of each input/output pin on the Arduino. In order to do this, we need to use shift registers which allow each pin of the Arduino to be able to control more LEDs and speakers than they would be able to without the shift registers. We chose to use Goldstar 74HC164 shift registers because they only need 2-5 volts to run and are compatible with Arduino microcontrollers. Using these shift registers will further the capability of the Arduino microcontroller by enhancing the amount of LEDs and speakers the Arduino can control and it also takes some of the load off the Arduino by storing some memory itself.

![Goldstar 74HC164 Shift Register](image)

Figure 9: Goldstar 74HC164 Shift Register

Each Goldstar 74HC164 shift register will be wired to the Arduino Mega microcontroller via the input/output pins. Each shift register will increase the capabilities of each Arduino pin by allowing for more speakers and LEDs to be connected to the Arduino. These shift registers are crucial to the success of our design because we need to be able to control the activation of all seventy seven speakers and LEDs and the Arduino Mega 2560 alone would not be able to control all of them.
1.2.7 Electrooculography (EOG) Electrode System

In order to examine the rapid eye movements of the subject under examination, we need an accurate way to record eye movements in response to the auditory and visual stimuli. An EOG electrode system is an accurate and well proven way to record rapid eye movements. In our system, two electrodes will be placed on the sides of each eye and one will be placed right above the nose in the center of the forehead. The electrode placement was shown previously in Figure 1. The EOG signal will be inputted into a computer in order to display the recorded eye movements in a way that can be analyzed.

The EOG system will be used to record the eye movement velocity and eye position during the examination. The position and velocity of the eye movements in response to the auditory and visual stimuli will be displayed on the computer through a LabView program which will display the recorded eye movements in a user friendly manner so that the data can be used for further analysis.

In order to test the accuracy of the EOG system, we will hook up the EOG electrode system to different members of our group and run trials. We will test eye movements in every direction and at every angle to assure that the test setup is sufficient in recording all possible eye movements.

1.2.8 LabView Program

In order to analyze the recorded eye movements, the eye movement velocity and position needs to be displayed in a user friendly manner. Our LabView program will input the signal from the EOG signal and will display the eye movement velocity and position in numerical and graphical form so that the data can be used for further analysis.

2. Realistic Constraints

Our device will follow all engineering protocols and standards and the design will be safe and provide our client with a device that meets his needs and fulfills all requirements. Our device will be innovative and unique and will provide our client with the first device of its kind.

2.1 Health and Safety

Since our device will be testing patients with possible mild traumatic head trauma, it is very important that our device does not compromise the health or safety of the patient being tested. Our device can not pose any potential threat to cause more damage to the patient’s
head. Our device requires no headgear and the only possible threat are device can cause physically to the patient’s head is during the application of the EOG electrodes. Our device will come with instructions for the operator to be very gentle when applying the electrodes to the patient’s head. The electrodes should cause no pain or discomfort to the patient’s head during testing as long as the operator applies them correctly.

Another potential safety risk of our device is that our device is run with flashing lights and sounds. The flashing lights and sounds may cause discomfort to the patient. The flashing lights may induce seizures to patients who suffer from seizure disorders such as epilepsy, so it is necessary to limit the use of the device so that people with such disorders cannot be examined using the device. In order to prevent any seizures during the usage of our device, the LED lights will not flash at a rapid pace that would cause potential discomfort to the patient. The lights will also be set so that the brightness does not overwhelm or cause discomfort to the patient. Our device will be made to use while the patient is seated which increases the safety of the device because in case the patient gets dizzy or light headed, they have a lesser chance of passing out or fainting if they are seated.

Another possible safety and health hazard of our device is creating loud noises that may cause discomfort to the patient. Our device needs to be able to create sounds that are clearly audible to the patient, however the noises cannot be so loud that they cause discomfort to the patient. In order to prevent our device from needing to produce loud noises, the device will be used in a quiet room with minimal background noise.

2.2 Manufacturability

A manufacturing constraint of this project is the time it will take to manufacture the device. Because our device has so many speakers and LED lights, a lot of wiring is required and because there is not a lot of space between each set of speakers and lights, a lot of intricate wiring will be needed. Then wiring that will be required to connect each LED and speaker to the shift registers and Arduino will be very detailed and may cause problems when building the device. Also, the cut that needs to be made around each LED needs to be very precise. This may take some time in assuring that each cut is perfect and efficient for our design.

2.3 Ethical

During the production of this device, ethical procedures will be followed. All procedures will follow engineering standards and no unethical testing will be done during production. All testing will be pre-approved and all research will be done with the upmost honesty.
2.4 Environmental

The device will be used indoors and will be powered using a computer so there are no real environmental concerns during production of our device.

2.5 Sustainability

Over time, as the device is used it is possible that LED lights and speakers may no longer work properly after several uses. Maintenance may have to be done over time on the device including rewiring, replacing LEDs, replacing speakers, and replacing shift registers. No other concerns regarding sustainability should be taken into consideration.

2.6 Social/Political

In general, athletes are not accepting of the idea of a prolonged absence from their sport. Although, the device will be beneficial to the health of athletes, many athletes would rather risk further injury as opposed to not participating in their sport for a prolonged period of time. Many athletes would be opposed to the idea of the device and this is a very important social constraint that must be considered. It will be beneficial to offer an education program in order to enlighten these about the risks and long term effects of mistreating concussions.

3. Safety Issues

Because the patients our device will be dealing with have potential mild traumatic brain trauma, one main safety issue is the prevention of causing any more damage to the head of the patient. Our device uses no headgear and the only contact our device makes with the patient’s head is through the EOG electrodes. Because the EOG electrodes are lightweight and typically cause little to no discomfort to patients, our device should be sufficient in causing no further damage to the patient’s head. Another issue involving the fact the patient may have mild traumatic brain injury is that there is a strong possibility that the patient may be dizzy, light headed, and may possibly have other symptoms associated with brain injuries. Due to these possible symptoms, our device will be designed so that the testing will be done while the patient is seated. This will prevent the patient from being injured if they faint or pass out during testing.

In order to prevent from the user from being endangered by electric shock, all electrical parts of the design including wires, circuit parts, and the shift registers will be covered completely by a combination of the black board and the black foam protective layer. The Arduino microcontroller which controls the activation of the speakers and LED lights will be encased in a shield. A shield is a plastic housing which encloses all of the Arduino’s electrical components preventing the user and patient from making any contact with them. The shield is also beneficial because it allows Arduino to still be able to connect to the computer via USB cable and also allows access to the digital input/output pins.
There are no real threats to the environment caused by our device. All components of the device are able to run off of the computer that they are connected to. The LEDs and speakers do not require any other power source to be activated which prevents the need for a power source that can negatively affect the environment.

4. Impact of Engineering Solutions

Our client, Dr. John Enderle will use our device to collect data on the rapid eye movements of patients and use the data to be able to accurately diagnose mild traumatic brain injury. Dr. Enderle has spent the last thirty years focusing his research on rapid eye movements and their corresponding neuronal activities. He is now in the stage of his research where he believes it is possible to accurately diagnose mild traumatic brain injury if he can gather data of the eye movement response to auditory and visual stimuli of a patient. Our device will be able to produce auditory and visual stimuli at various locations and angles and will be able to display the patient’s response in a manner in which the client can use the data to further his research.

Using our device, our client will be able to become the first researcher in the field to study the rapid eye movement response to auditory and visual stimuli simultaneously. Using the data gathered from our device, our client can become the first researcher to make the quantitative link between the rapid eye movement response of a patient and the diagnosis of mild traumatic brain injury. Most concussion tests on the market today involve cognitive and memory based tests. These tests provide no quantitative data to support the diagnosis of mild traumatic brain injury.

There are over one million people a year who suffer from concussions in the United States alone. If a person with a concussion is diagnosed accurately and quickly, there is a very strong chance that they will recover fully and have no long term symptoms. However, if a person is not diagnosed or diagnosed improperly, they will likely suffer from long term problems such as severe headaches, fatigue, dizziness, confusion, memory problems, sleep disorders, and sensory problems such as vision and hearing disorders. Many athletes and members of the military do not want to sit out from their sport or duty for a prolonged period of time. Due to most of the concussion tests on the market today having no quantitative data to support their diagnoses, many athletes and members of the military are able to cheat the tests so that they do not have to sit out of any competition or service. These people can easily cheat these concussion tests by giving false responses to questions. Our device will eliminate the possibility of people cheating concussion tests because the device will provide quantitative data to accurately diagnose concussions. There is a huge need in today’s world for a device that is able to do this and if our device is successful, it could become the new standard for diagnosing mild traumatic brain injury.
5. Life-Long Learning

Throughout the process of completing our design we have acquired a vast amount of important knowledge that we will be able to not only use throughout our lives as engineers, but we have learned valuable life lessons that we will be able to use in our everyday lives in the future.

Throughout our research that we have done when coming up with the design for our device, we have accumulated a vast amount of knowledge regarding mild traumatic brain injuries, different types of treatment for such injuries, the effects of such injuries, and prevention of these injuries. The information we have gathered over the course of our research will be very useful for the future due to the incredible need in today’s world for knowledge of concussion diagnosis, treatment, and prevention.

Due to our device using an Arduino microcontroller, we will learn how to be able to program these microcontrollers which will be valuable in the future. Another benefit of using an Arduino microcontroller is that it is programmed using C programming language which is used in various ways in the engineering community. Using shift registers will also give us valuable knowledge because they are also used in many applications in engineering. Circuit design in general is a very tedious process and the ability to create a successful circuit will lead to us acquiring useful life skills such as proper circuit building technique, troubleshooting, and patience.

In order to create a successful device, we will need to plan properly, budget our time and money, use resources to their full potential, and properly document our plans, acknowledgements, and device modifications. These skills are very valuable in life and this project provides us a great learning experience in which we will be able to apply these skills in the workplace in the future. This project will also teach us to use Microsoft Project which is a valuable skill that can be used in future projects. This project will also provide us with valuable teamwork skills that will be necessary in industry, the process of designing and building our project replicates the engineering process in industry and the skills we gain during the process will be very valuable to our lives in the future.
6. References

http://www.instructables.com/image/FNM4193G1ZGOPNG

