

Prototype for Assessing Concussions Using Eye-tracking

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Abstract: With increasing amount of head injuries involved in sports there has been emphasis on creating a new concussion assessment method in order to increase accuracy and objectivity of diagnoses. Current methods of concussion assessment rely mainly on a subjective assessment of eye movement by a doctor. These tests are prone to interpretation and bias on behalf of the physician. Our device aims to remove this subjectivity and replace it with a conclusive, objective score to determine the presence and severity of a concussion. The objective of this system was to create a project that could use eye-tracking to determine quantifiable and repeatable numbers to determine a concussion. Using a Tobii Camera to track eye movements and blinks we tested subjects with five tests to target and stimulate different portions of the brain and visual processing complexes. Our device aims to provide objective tools to hasten the diagnoses of a concussion.

Keywords: Concussion, Eye-Tracking, Tobii Camera

1. Introduction

Our project aims to diagnose the presence and severity of a concussion. It is important to understand the physiological conditions that give rise to and are caused by concussions. A concussion can simply be defined as a traumatic brain injury which disrupts the normal functioning of the brain. Current applications of assessing concussions involve a doctor's subjectivity following a series of tests. The goal of this project is to create a device that objectively quantifies a concussion using eye-tracking technology. Additionally, our project should be easily repeatable for desirable results. For the assembly of our apparatus, our team used a wooden base, a twenty-nine-inch monitor, a Tobii 4C camera, linear actuator and a 3D printed chinrest. The project sponsor emphasized using modern eye tracking technology from Tobii, maximizing accuracy and improving the precision of data. Our methodology utilizes simplicity for any user to run the device. The concussed individual will set their chin in place and follow a series of eye tests displayed on the monitor. Ultimately, this project would be used in various applications to quickly assess concussion of athletes on the sideline, in hospitals, and emergency vehicles.

In recent years concussions have had a rise in media attention due to an increasing awareness of complications associated with repeated head injuries. In the summer of 2017, Boston University conducted a study of deceased football players. The study concluded that 110 out of 111 deceased NFL players had developed Chronic Traumatic Encephalopathy (CTE), a degenerative disease linked to repeated blows to the head (Mez et al., 2017). Currently, testing for this disease can only be performed on a patient who is deceased. This data suggested that CTE is much more common in football players than previously thought. CTE may present itself in patients as Alzheimer's, Parkinson's disease or dementia. Other symptoms of CTE include memory loss, confusion, impaired judgment, impulse control problems, aggression, depression, anxiety, and suicidality. Media attention for concussions further increased due to the NFL Concussion Settlement in the summer of 2017 (Mez et al., 2017). This mass tort lawsuit involves 20,000 retired/deceased NFL player which were settled to pay afflicted NFL players one billion dollars.

2. Design Overview

There were many different requirements considered throughout the design process. Within the design process there was consideration for environmental, ethical, economical, health and safety, sustainability, usability and customer requirements. Our first step was doing research to understand which concussion tests should be chosen to be implemented in PACE. Relating a specific area of the brain to a certain test will allow for trainers to diagnose what specific area of the brain may be injured. The next greatest challenge was to determine how to successfully implement the five test that were chosen while maintaining portability.

Original designs consisted of two monitors to allow for maximum field view for patient testing. However, monitors contain heavy metals and toxins which cannot be easily recycled. To reduce the amount of these chemicals that enter the environment upon disposal, the two monitor setup was changed in favor of a single monitor with a mechanical portion for the convergence and divergence test. The monitor selected is an ultra wide 29 inch. To minimize the energy consumption of this, an energy star certified monitor was chosen. By replacing the dual monitor setup with a single one, and choosing an energy efficient option, waste and energy consumption were able to be reduced.

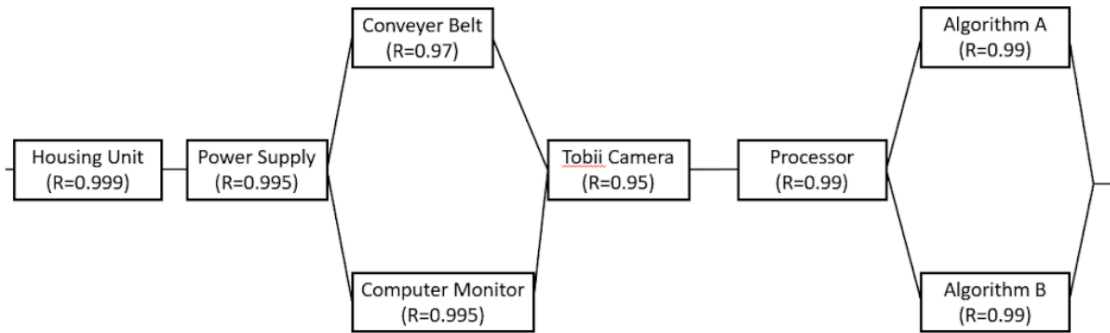
Another aspect of the design where the environment was considered is in the selection of the material to construct the housing unit. Initially, plastic was considered, however, wood was settled on. While plastic is highly versatile, it can sometimes be difficult to recycle. To use plastic, new material must be introduced into the supply stream, and upon disposal, the plastic has a higher chance of causing environmental damage. The wood that is going to be used will be reclaimed. In this way, no new wood is entering the supply stream. Additionally, the wood will be able to be returned to the consumer cycle after the completion of the project. To ensure that the wood is able to be re used, the method of joining was considered next. Initially, wood glue was proposed to secure the joints in the box. However, after consideration, screws were chosen. By utilizing screws, the wood can be easily separated and recycled. If wood glue would have been used, separation of the pieces would be near impossible without damage. An additional advantage of screws lies within the trouble shooting phase. If a problem occurs with the internal mechanics, screws allow for quick disassembly of the unit and rapid repair. If glue was used, the pieces would be permanently fused, not allowing for adjustments or repairs. One final consideration was in the selection of the mechanical convergence and divergence test. Initially, a DC motor was considered to move the object. To mitigate drawbacks, such as the inability to hold a long aluminum rod with a ball at the top an alternative idea was suggested. A linear actuator would be used instead. This linear actuator has the ability to move the object with comparable accuracy. One drawback is the lack of positional information, there is no way to tell where exactly the object is. To combat this, a ruler will line the length of the linear actuator to determine where it has been stopped.

By closely analyzing the major components of the design, we were able to propose more environmentally compatible solutions. By using one energy efficient monitor over two, screws over glue, wood over plastic, and a DC motor over a linear actuator, our design minimizes any potentially harmful environmental impacts it may have.

One of the most important qualities for any designed product is its reliability. If it is not a reliable design, it will fail quickly and not fulfill the client's needs. Figure 1 shows our assessment of the devices reliability, or the likelihood of failure of the device. Each component of the system needs to perform in a predictable and reliable manner to ensure a successful device. To increase reliability, systems can be placed in parallel, providing two paths for the process to proceed, reducing the reliance on any one system. By placing processes in series, a decrease in reliability can be observed. With all processes following, a failure at one point would result in the complete failure of the entire system. This system must be extremely reliable and precise to ensure that the correct conclusions are drawn. Even a slight error in eye movement recording, or calculations may result in a false positive or negative. These errors could lead to unnecessary treatment, or potentially the lack of treatment of a mild traumatic brain injury. The following figure, our methodology for determining reliability and percent chance of failure can be seen.

The first component in the system is the housing unit. With solid construction, this portion of the design should have very little chance of failing barring a catastrophe. Next, the power supply, designed for consistent and steady power, has an extremely low chance of failure. The tests follow, with a split in the path. The linear actuator will be used for the convergence and divergence tests. This component has minimal complication except for the possibility of the red ball being broken off by force. The computer monitor will be used for the other four tests, with its function independent of the linear actuator.

The monitor, like the power supply, runs a very low risk of failure. Next, the Tobii camera. While the camera in terms of hardware is relatively reliable, it has shown to be touch and go in locating the eyes in isolated circumstances. This block is the biggest sticking point in the system, with the timing and score hinging on its success. The computer processor is an extremely reliable component, used by millions of people every day without failure. Lastly, the algorithms for calculating score. With two independent methods of calculating a score, we reduce our reliance on one block of code. If any bugs may arise, the other algorithm will be able to cover any deficiencies in the other section of code. As seen in the calculation above, the device has a predicted reliability of around 93.5%. This is one of the many reasons as to why we chose these components and design.



$$RT = (0.999)(0.995)(1 - (1 - 0.97)(1 - 0.995))(0.95)(0.99)(1 - (1 - 0.99)(1 - 0.99))$$

$$RT = 93.5\%$$

Figure 1. Device Reliability

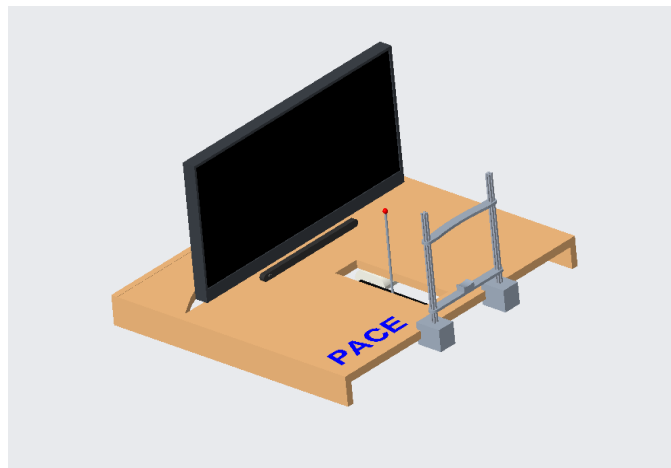


Figure 2. CAD Diagram

3. Testing

Our project will detect and quantify concussions in order to allow someone who has suffered from a head injury in a given activity to make informed decisions on whether they should continue to participate or should rest and recover. In addition, detecting the presence of concussions is the first step to minimizing their occurrence. PACE will determine a concussion by performing a series of five visual tests that track eye movement. These tests are normally performed by an athletic trainer or a doctor on the sideline of a field. Due to this test being performed by a human there is intrinsic subjectivity between test. PACE aims to eliminate this subjectivity to allow objective comparisons between different concussions.

The Tobii camera has the ability translate gaze data into a cursor position. This cursor position can again be translated into a X and Y coordinate value using code generated by our team. Cursor position on the screen will be recorded once every millisecond as long as the test is being administered. With data stored in plain text, it is anticipated to take up less than 1 megabyte of random access memory, mitigating any concerns regarding storage space. Each test run will be a variety of shapes moving across the screen or held stationary. These shapes are coupled with a desired gaze area where the patient is expected to look. The X and Y coordinates of these bounds as well as area within, will be recorded. To analyze for abnormalities in gaze, the cursor position will be compared to the desired gaze area. To ensure that the test will accurately reflect each condition of the individual, a pre and post concussion test will be administered. This will help gauge, under

normal conditions, how long the individual is able to maintain the cursor in the desired gaze area. Then, by administering a post assessment, deviations in this time can be analyzed. Individuals who are unable to maintain the cursor in the desired gaze area for a near equal amount of time will produce a higher score.

The value of the score will arise from the differences in time the cursor has spent in the desired gaze area. Therefore, a higher score will correspond with a higher likelihood and higher severity of concussion. Every millisecond spent out of the desired gaze area will correspond to one point. Testing will need to be performed to establish a baseline score. By running a pre and post test on healthy individuals, a healthy, baseline score can be developed. This scoring system will be summated across all 5 tests, but will also be applied to each individual test. The scoring values of the individual tests can give insight to the presence of any localized brain damage. Each test is controlled by a different area of the brain, and poor performance on one test, and not the other would grant valuable information about damage to the brain.

In order to test the ability of the eyes to converge and diverge one part of our design must incorporate an object moving towards and away from the patient's eyes. At first we thought that this could be simulated by tilting a monitor toward the patient and having them follow a point on the screen that would move on an angle towards them. However, after experimentation it was determined that in order to have the same effect as a proctors finger moving toward and away from the patient we would need to have an object move in a linear path orthogonal to the patients face. For this object to repeatedly move in the same path it was determined that either a linear actuator or a DC motor attached to a belt. However, after the project is assembled and we begin testing and we opted to use the linear actuator due to its ease of use. The proctor will ask the patient to concentrate on the red bead while the test is performed.

As this prototype is specifically designed to test for small, minute eye movements, our objective was to isolate this phenomenon as much as possible. By implementing a chin rest, our goal is to reduce all movement of the eyes to the influence of ocular muscles, and not of head movement. The chin rest is 18 inches tall, and has an adjustable chin piece and head piece. The adjustability allows for comfort in all shapes and sizes of users. Supported by smooth surface T slotted bars and anchored to the base of the device, providing a high degree of stability and strength. The actual pieces of the chin rest composed of 100% fill 3D printed SLA plastic. This type of printing vastly increases the strength of the final product when compared to more traditional methods such as ABS or PLA plastics. This method also greatly reduces the striated appearance associated with most 3D printed objects. This chin rest will provide vastly improved accuracy and repeatability. With the eyes remaining at the same x and y position, it will be significantly easier for the Tobii camera to track their position. This will serve to fulfill our main goal of improved accuracy and repeatability.

The PACE test aims to mimic the tests which traditionally are given by a doctor or an athletic trainer to determine if a patient is concussed. PACE aims to eliminate the subjectivity of these tests by having a repeatable test. PACE will conduct a series of five tests where each test will be compared to the score from the preliminary test. The first test that will be conducted is for smooth pursuits. During this test the subject will follow a slow moving object through space in the formation of the letter H. This requires the patient to shift their attention without moving their head. The superior colliculus controls motor neurons responsible for this eye movement. So, if a subject displays any abnormalities in this test the superior colliculus which is a part of the midbrain may be affected. The second test will be saccades which involves rapid eye movement between two fixed points on the screen. This movement is controlled by the frontal-supplementary eye field located on the dorsal medial frontal lobe of the cerebral cortex. The next test will involve targets to be randomly highlighted on the screen every few seconds and the subject will be asked to quickly focus on the small target. During this test we can expect a patient who is concussed to display hypermetria and hypometria which is overshooting and undershooting of the eyes to the target. If this occurs the eyes will then adjust themselves to focus on the target. The ability to track converging and diverging targets will then be tested for using the linear actuator with an aluminum rod and red bead located at the tip. This motion is initiated by the mesencephalic reticular- process and is carried out by motor neurons in the basal plate. The last test that PACE will perform is the optokinetic tape test. This test will be done by red and black stripes moving across the subjects field of vision across the patient's line of vision while asking the patient to only focus on the red stripes directly in front of them. This tests both slow and rapid eye movement. The eyes must track the red box across their visual field and also move back to the original position where the red stripe was first seen. This reflex ability to quickly focus on where the red box was originally located is called an optokinetic nystagmus (OKN) and is controlled by the pretectal area-pupillary light reflex. These test mimic the tests which are traditionally provided by an athletic trainer but will have better accuracy for tracking the eye movement. The calculation completed with allow for a quantifiable judgment of a concussion.

The Tobii camera presented a 99% accuracy with gaze according to the Tobii pro testing summary (Tobii, 2017). Studies from the American journal of emergency medicine show that approximately 16% of head injuries that met the World Health Organization's concussion criteria did not result in a concussion diagnosis. Patients with a longer length of Emergency Department stay were less likely to receive a concussion diagnosis (Bowen, 2003). The use of the Tobii camera will minimize the inaccuracy of diagnosing concussions that may be seen in the emergency department. Previous designs included testing with a web camera. The inability to track the eye gaze of the patient made the web camera not a feasible option.

PACE has the ability to be purchased as one system compared to other systems such as ImPACT and MMC concussion test produced by other companies. Many of these test are priced per test which can become very expensive when implemented in a high school with a large amount of students. Purchasing a few systems of PACE will allow for a cheaper diagnosis of a concussion.

4. Conclusion

We explored a variety of possible approaches for monitoring eye movement, from web cameras to a Tobii camera. Ultimately, we settled on the Tobii camera due to its superior eye tracking capabilities and built in software, saving significant development time. We established a series of 5 tests to determine the presence and severity of a concussion. These tests include: saccades, random motion, convergence and divergence, optokinetic tape, and smooth pursuits. These five tests are designed to mimic those administered by a doctor after a potential concussion. The running of these tests will produce a score based on the amount of time the user spends looking outside of the target. With an established baseline score, we will be able to determine what a healthy and concussed range of score will be. Our device will be capable of not only collection of data, but interpretation of the data into a composite and objective score. The score generation will allow us to achieve our final goal of reliable, accurate, and objective concussion diagnosis. We aim to begin testing as soon as possible due to resource restraints. This phase will most likely take the longest as there are almost certainly going to be unanticipated roadblocks to the successful completion of our project in this phase. With software bugs dealt with, we will begin testing and data collection. Each member of our group will subject themselves to the series of tests. They will then wait around 24 hours. As long as no brain trauma was sustained in this time period, a healthy difference in scores can be generated. By creating a pool of data regarding scores and eye timing, we will be able to create a baseline data set to compare future patients. If a healthy score can be determined, further deviation above the score can be indicative of the presence and severity of a concussion. The data collection and testing phase is crucial to our proof of concept.

In theory, each test would contribute to the user's score and help conclude the severity, but some tests may be worse or better depending on the individual's reflex abilities. Although these tests are objective, there will be varying subjectivity based on the subject's innate ability to perform these tests. The team plans to use non concussed members to create sample data, and to use concussed patients to create the experimental group data. It is important that any continuation of this project in the future understands that we do not have data before and after an injury from a patient, and that before and after data will show true correlation.

This device would revolutionize the current method for testing concussions if successful. Currently, the way concussions are checked for is by a doctor moving a light in front of a patient and watching their eyes. This method is very subjective and has no baseline for normal performance. If PACE can successfully quantify concussions this will allow objective comparison of different head injuries. Objective comparison will allow us to advance our understanding of head injuries. Since concussions have evoked much commotion regarding the NFL, successful manufacturing and mass distribution of PACE could be very lucrative. Another implication of PACE would hopefully reduce the number of people who develop CTE due to concussions. People who are prone to concussions would have access to the PACE test to allow them to make more informed decisions on continuing to put themselves in concussion prone situations i.e. playing football.

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