Establishing a Relationship Between VOMS Performance and Changes in EEG Signatures for a Rapid Assessment and Diagnosis of Concussions

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Abstract

This study aims to discover a possible relationship between electroencephalogram (EEG) signature changes as physiological indicators of one's current state, and performance on the Vestibular Ocular Motor Screening (VOMS) assessment. A Muse 2 generated a baseline EEG scan for each participant, allowing for the collection of data associated with one's brain activity. The subjects were then taken through several VOMS domain tests with a continued recording by the device. A comparable analysis was conducted between the participant's baseline recording and VOMS recording with an intent to identify the consistent correlations in between. In conclusion the findings of this study show potential for characteristic brain activity patterns dependent upon what VOMS domain is being tested. Therefore, when any deviations from those features are observed, the likelihood of the presence of a concussion is much greater.

1 Introduction

Traditionally, brief assessments used to diagnose concussions have been very inconsistent and unreliable. Common methods of diagnosis are a CT scan or MRI. Although they are accurate, these methods can take time to process, which can be a problem because numerous studies have shown that concussions result in nearly instant changes in brain functioning. Thus, if it is not addressed appropriately and in a timely manner, many bad decisions can be made that negatively impact the health of the brain. Second Impact Syndrome (SIS) can result from this, and with repetition, it can lead to the development of chronic neurodegenerative diseases such as CTE. Many of the current sideline concussion assessments are intrinsically subjective and rely heavily on the presence of symptoms. Examples of such tests include the Post Concussion Symptom Scale (PCSS) which makes use of the Guttman scale to assess symptomology in categories such as emotion, sleep, and cognition. There is also the Graded Symptom Checklist/Scale (GSC/GSS) which again uses the Guttman scale to explore symptoms within, cognitive, somatic, and neurobehavioral domains (Graham, 2014). There are other methods that may holistically evaluate concussion induced impairments to produce more concrete results by testing performance on neurocognitive tests but they take too long to conduct and there are many factors that could affect performance on these tests. Examples include CNS Vital Signs test, Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) and Concussion Resolution Index (CRI) (Graham, 2014). Lastly there are some quick and somewhat reliable methods that have been used to determine the presence of a concussion but the results are too limited to suggest that they are completely competent in achieving their goal (Anzalone et al., 2016). Examples of these methods would be the King-Devick test which evaluates impairments in saccadic eye movements, and the Balance Error Scoring System (BESS) that exploits dysfunction in the vestibular system as well as the processing of visual and somatosensory information (Graham, 2014).

2 Background

In our study we hope to discover and develop a possible relationship between EEG signature changes and performance on Vestibular Ocular Motor Screening, also known as VOMS, which in recent years has been developed in hopes of more accurately diagnosing concussions. If a relationship does exist, this method could be useful in accurately diagnosing concussions immediately after the incident occurs. Many studies in the research community have that shown concussions and traumatic brain injuries (TBI's) alter brain activity, specifically TBIs can result in changes to the amplitude of the frequency bands of the EEG signals, supporting that there are some physiological changes that take place post-TBI (Guay et al., 2018). It is also known that concussions can cause bleeding and bruising in the brain thus altering the flow of blood within. With the help of fMRI's it has been determined that blood flow is indirectly related to brain activity creating a possibility for changes in blood flow to manifest in the form of altered EEG signals. A recent study has produced results that strongly support altered EEG activity due to the presence of a TBI. In this study the researchers aimed to observe differences in EEG activity between concussed and healthy individuals during three conditions, eyes closed, eyes open, and vigilant task. What they [the researchers] found was that "Athletes in the concussed group exhibited an increase in delta and theta bands, and a decrease in alpha, beta and gamma frequencies compared to their uninjured peers during all three testing conditions" (Munia et al., 2017). This suggests that changes in EEG activity may be a good indicator of the presence of a TBI. TBI's also effect and sometimes impair the neuroarchitecture of the brain and various neuronal networks, specifically the vestibular and oculomotor system responsible for functions such as balance and eye movements (*Diagnosing concussion with image tests* 2018). For the scope of this study we will focus on damages that occur primarily to the vestibular and oculomotor systems. The impairments that result from damage to these systems often lead to physiological symptoms such as headaches, dizziness, nausea, and changes in vision. Some research has been done to show that 40%-50% of concussed athletes experienced dizziness and impaired balance, which is related to the vestibular system, and 65% - 90% of concussed athletes expressed deficits in oculomotor functioning (Moran et al., 2018). The VOMS method takes advantage of these symptoms and uses them as a basis in determining if a concussion is present or not. Within the VOMS there are six 'domains' that are tested; Smooth Pursuit, Horizontal Saccades, Vertical Saccades, Near Point of Convergence, Horizontal and Vertical Vestibular Ocular Reflex (VOR), and Visual Motion Sensitivity. The screening is conducted by initially having the subject rate their physiological symptoms of headache, dizziness, nausea, and fogginess, on a standard Likert-type scale from 0-10, to establish a baseline. Then, after each domain is tested, have them rate their symptoms again, the results of these tests are known as provocation scores (*What Is Vestibular Ocular Motor Screening?* 2017). The VOMS and its results were desirable for several reasons.

Internal Consistency: A study showed that when the results were subject to a Cronbach alpha analysis to determine the relationship between each individual symptom score, and how positively correlated they were with each other, as well as to the entire VOMS. The result was a Cronbach alpha value of 0.92, which indicates that overall, the VOMS has a rather high internal consistency (Goforth, 2015). It was said that "This finding suggests that the VOMS items measure related, but not identical, components of the vestibular and ocular motor systems." (Mucha et al., 2014)

Uniqueness: The VOMS was also selected because it provides a unique diagnosis of concussions that has not been implemented in other concussion assessment tools. Other tools either do not assess vestibular and oculomotor function at all, or don't test it completely, thus they are missing an entire region of impairment in their diagnosis. Though the VOMS method is unique, it still should follow similar trends that widely accepted tests exhibit. To support this, studies have shown that the VOMS scores are positively correlated with the PCSS total score and are negatively correlated with neurocognitive test performance (Mucha et al., 2014). These correlations help increase the validity of the VOMS method because they show that though the VOMS assesses a different aspect of brain impairment, it is still related to the other methods out there.

Accuracy: The VOMS test is favorable due to its high accuracy when compared to other common concussion protocol tests. A study that compared test performance and test-retest reliability of the VOMS and the King-Devick test used multivariate base rate analyses and a series of chi-square tests to determine the difference in false-positive rates between the two protocols. What the study found was that while the King-Devick test produced false-positives 36% of the time, the VOMS produced false-positives only 2% of the time (Worts et al., 2018). If those false-positive trends can be replicated, then the VOMS would prove to be an extremely accurate method compared to what is currently being used today.

One thing that is particularly great about the VOMS is its proven effectiveness in youth athletes. A study was done to show that VOMS can be applied to many age groups, having shown accurate results in athletes that are as young as 8 years old when testing for internal consistency/reliability, and false positive rates (Moran et al., 2018). This is promising because the end goal of our study aims to make a device that is user-friendly for all ages, especially the youth population who receives less attention and guidance from health/medical professionals as older collegiate and professional athletes do. This trait gives the VOMS an advantage over some other common concussion assessment tools that might be limited to age of optimal effectiveness. Tools such as the PCSS and the GSC have been suggested to be limited to concussed individuals who are 12 y.o. or older and 13 y.o. or older, respectively (Graham, 2014).

The overall capabilities of the VOMS to detect the presence of a concussion was one of the most important factors in choosing it (the VOMS) over any other concussion assessment tool for our research study. Aside from brain imaging scans, the

VOMS appears, at face value, to be the most accurate method for identifying concussed individuals within a mixed population containing both concussions and non-concussed individuals. A recent study showed that all associated VOMS sub tests, such as NPC or VOR, are significantly associated with the likelihood of concussions. The study went on further and discovered that individuals with concussions had significantly higher provocation scores on all of the VOMS domain tests that were given, with respect to non-concussed individuals. It also found that a symptom provocation score of 2 or greater on a single VOMS domain test increases the probability of being concussed by at least 46%, thus totaling at about a 96% probability of a concussion being present (Mucha et al., 2014). This gives us the freedom to conduct our study without testing every domain of the VOMS if we see it fit, due to the strength of each individual domain in identifying the presence of a concussion.

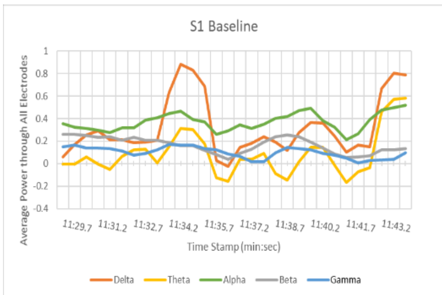
It can be concluded that although related, each domain is uniquely involved with the vestibular and/or oculomotor system thus collectively they produce a non-overlapping group of results that can determine the likelihood of a concussion. It is important to clarify that this study is not suggesting that the changes observed in EEG signals are derived from, or the product of, vestibular and oculomotor dysfunction. We are simply using the accuracy of VOMS to our advantage as a means of validating if a concussion is present when changes in EEG signals occur. To date there are no clinical tools that incorporate the VOMS assessment in their diagnosis of concussions expressing a need for one to be developed. Thus, if a relationship between EEG and symptom provocation scores on the VOMS test can be established, then there is a realistic potential for this method of a “sideline diagnosis” to become the new standard in concussion assessment.

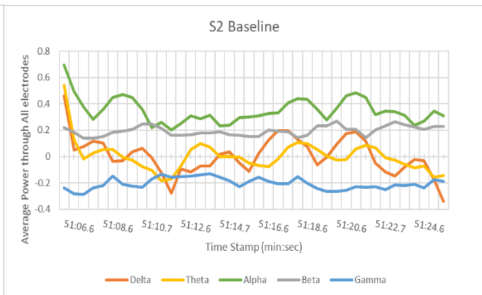
3 Method and Study

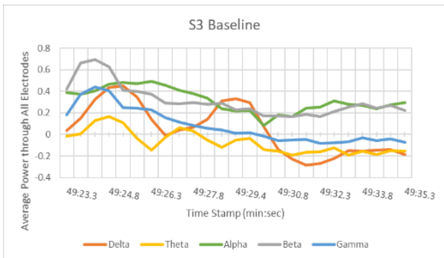
To conduct our study and discover a relationship between EEG signal changes and VOMS provocation scores, we plan to use the MUSE Brain Sensing Headband to collect the EEG data, specifically the Muse 2 device. Numerous research studies have shown that the MUSE is capable of detecting changes in EEG brain activity and frequency band power. In conjunction with the MUSE, the Mind Monitor app will be used, which will present that data as raw EEG activity and allow for the band power of each frequency to be observed in real-time. The process of data collection will include selecting available athletes and then taking each individual through selected domains and their associated tests. In the initial study, we gathered 3 student-athletes at the University of Texas at Austin. Participants were between the ages of 19-22 years old and participated in various sports, the initial study included 2 male and 1 female participant(s). For each participant, a baseline EEG reading was recorded; subjects were instructed to sit still with their eyes open while performing no ocular movements, they were also encouraged to refrain from blinking. After an initial EEG recording was collected to acquire a baseline reading of brain activity, the subjects were taken through several VOMS domain tests. The tests were horizontal smooth pursuits, horizontal saccades, vertical saccades, and visual motion sensitivity, thus 3/6 VOMS domains were tested. The NPC (near the point of convergence) test was excluded because the results of this test cannot be confidently related to brain activity patterns. The VOR (vestibular ocular reflex) domain(s) was also left out due to too many difficulties in the collection of data. No symptom provocation scores were recorded because all of the participants were healthy.

Data: S1, S2 and S3 correspond to subject 1, subject 2 and subject 3, respectively. (Note that in all charts power is measured in dB)

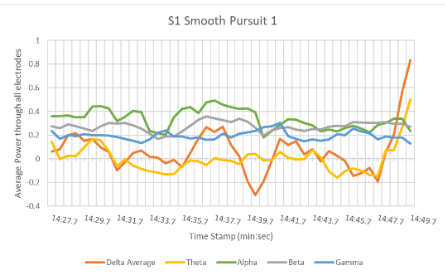
Baseline:

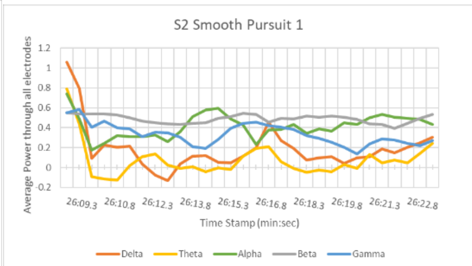


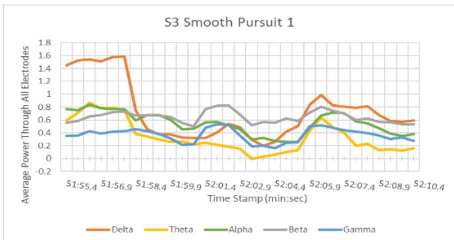




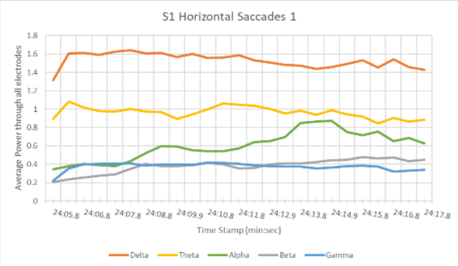
Smooth Pursuit (Horizontal): Subjects were instructed to follow examiners finger (held at eye level and 3 feet away from subject) as it moved 1.5 feet to the right and 1.5 feet to the left, with respect to the midline; 2 repetitions were recorded

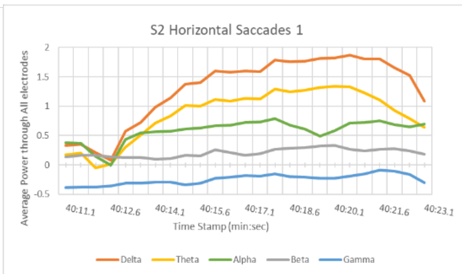


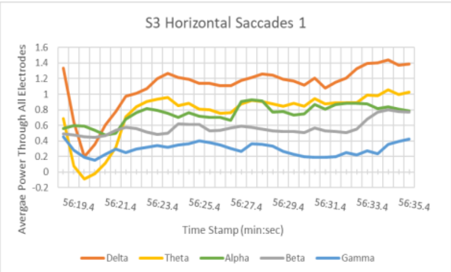




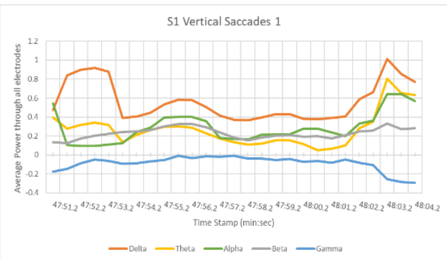
Horizontal Saccades: Examiner held both index fingers at a horizontal distance of, 3 feet apart from each other (distance between fingers split the midline of the subject evenly) and 3 feet from the subject (at eye level), then the subject was instructed to move both eyes (concurrently) from one finger to the next as quickly as possible; 10 repetitions were performed (midline → Left → Right → midline = 1 repetition)

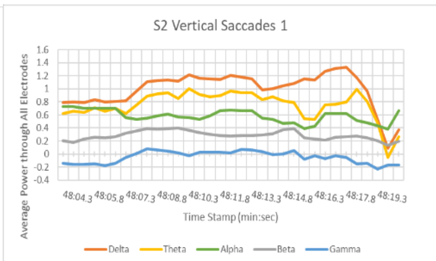


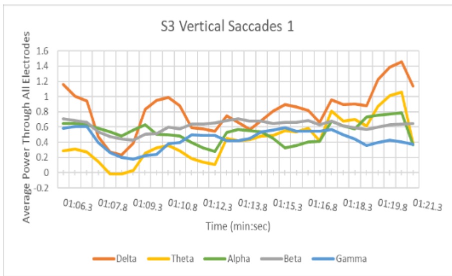




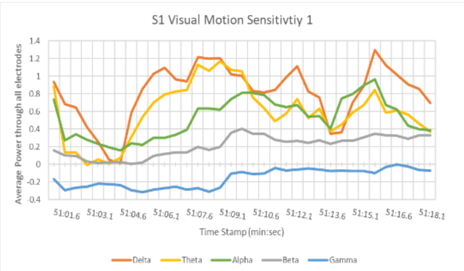
Vertical Saccades: Examiner held both index fingers horizontally at a vertical distance of, 3 feet apart from each other (with the middle being at the bridge of the nose) and 3 feet from the subject, then the subject was instructed to move both eyes (concurrently) from one finger to the next as quickly as possible; 10 repetitions were performed (midline → up → down → midline = 1 repetition)

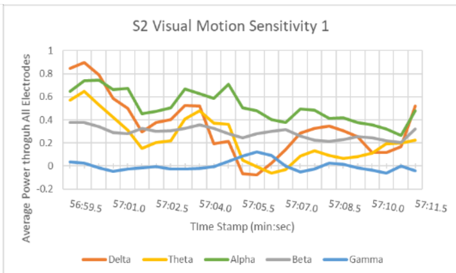


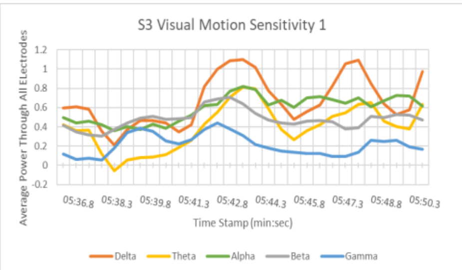




Visual Motion Sensitivity (VMS): Subject was instructed to stand up and extend arms out directly in front of them, interlocking their fingers with their thumbs pointing upward. Then, while keeping their eyes fixated on their thumbs, the subjects were instructed to rotate their trunk 80 degrees to the right and 80 degrees to the left to the beat of a metronome set to 52 bpm; 5 repetitions were performed (midline → Left → Right → midline = 1 repetition)







Discussion and Future Works

The charts above would represent baseline EEG signals after the performance of each VOMS domain test once the final study is conducted. Considering that all the data collected in this study were from healthy individuals (due to a lack of access to a concussed sample) there are no correlations to draw between concussions and the results produced in this paper. But the findings are still important because they show a potential for characteristic brain activity patterns dependent upon what VOMS domain is being tested. With more subjects to collect data from, one can see the possibility of discovering unique features of each VOMS test that are consistent across a large population of healthy individuals that can act as a standard/reference. Therefore, when any significant deviations from those features are observed the likelihood of the presence of a concussion is much greater.

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