# Preliminary Results of Residual Deficits Observed in Athletes with Concussion History: Combined EEG and Cognitive Study

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***Abstract*— Assessment, treatment, and management of sport-related concussions are a widely recognized public health issue. Although several neuropsychological and motor assessment tools have been developed and implemented for sports teams at various levels and ages, the sensitivity of these tests has yet to be validated with more objective measures to make return-to-play (RTP) decisions more confidently. The present study sought to analyze the residual effect of concussions on a sample of adolescent athletes who sustained one or more previous concussions compared to those who had no concussion history. For this purpose, a wide variety of assessment tools containing both neurocognitive and electroencephalogram (EEG) elements were used. All clinical testing and EEG were repeated at 8 months, 10 months, and 12 months post-injury for both healthy and concussed athletes. The concussed athletes performed poorer than healthy athletes on processing speed and impulse control subtest of neurocognitive test on month 8, but no alterations were marked in terms of visual and postural stability. EEG analysis revealed significant differences in brain activities of concussed athletes through all three intervals. These long-term neurocognitive and EEG deficits found from this ongoing sport-related concussion study suggest that the post-concussion physiological deficits may last longer than the observed clinical recovery.**

## I. Introduction

Mild traumatic brain injury or concussion is one of the most common incidents in high-impact games such as football, ice hockey, and rugby [1]. A Centers for Disease Control and Prevention study has reported that each year nearly 1.6-3.8 million sports/recreational-related concussions occur in the United States [2]. Also, data from the National Collegiate Athletic Association (NCAA) has shown that the rate of concussion is between 0.23 and 0.43 per 1000 athlete-exposures among high school and college athletes. Concussion is mainly caused by direct or indirect force to the head area and may result in temporary disorientation, confusion, dizziness, nausea, and a headache, with or without loss of consciousness, memory, or structural damage [3]. These symptoms are usually found a few weeks after injury and dissipate over time, but sometimes can persist for up to four years [4]. Recent publications have shown that a patient may be symptom-free during cognitive measurements but can show reduced brain function in neurological measures [4- 6].

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After concussion, the biggest challenge for coaches or medical personnel is the RTP decision. Premature RTP can result in further injury and even prolonged or permanent functional or cognitive deficits to the concussed athletes. Several researchers have given emphasis on clinical outcome measures like Concussion Symptom Inventory (CSI), Standardized Assessment of Concussion (SAC), Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), Balance Error Scoring Systems (BESS), and Automated Neurophysiological Assessment Metrics (ANAM). It has been shown that electroencephalogram (EEG) spectral features are changed for mild, moderate, and severe traumatic brain injury anywhere from 15 days to four years post-injury [4]. In [5], researchers conducted both quantitative EEG (QEEG) and clinical studies and summarized that the post-concussion physical recovery may take a longer period than the detected clinical recovery.

Concussion assessment is a challenge as many athletes show a tendency to underreport their symptoms. Moreover, no single approach appears sufficient for a sensitive and concrete concussion assessment. Our current study hypothesized that combining evaluations of multiple modalities such as brain alteration recordings and neurocognitive assessment can provide a set of characteristic "signatures". We believe that this collective approach will better determine not only injury severity and recovery timeline but it will also allow coaches to make sensible RTP decisions. In this preliminary work, a comparison of the neurocognitive and electrophysiological performance of athletes with no history of concussion to those athletes with previous concussion history was done. The goal of this comparison was to highlight any potential differences between these athletes 8 to 12 months post injury.

## II. Materials and Methods

### *A. Subjects*

A total of 6 subjects (male, mean age: 16.01±0.34 years, height: 1.76±0.08m, weight 65.52±7.85kg) were recruited for this concussion analysis study. High school athletes were selected as subjects since it is a well-established hypothesis that adolescent athletes are more sensitive to concussion than adult athletes, with prolonged symptoms and a lengthier RTP timeline. The study was restricted to football to align itself better with the highly publicized wave of concern about brain trauma in National Football League (NFL) stars. Written consent for participation was collected from the athletes and also from their parents or guardians. Each participant participated voluntarily in the study and had to complete a demographic information form with previous concussion history before data collection. All experimental protocols of this study were approved by the University of North Dakota Institutional Review Board (IRB).

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TABLE I. CHARACTERISTICS OF THE SUBJECTS

| Characteristics | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| Number of concussion | 2 | 1 | 1 | 3 | 0 | 0 |
| Loss of consciousness | No | No | No | No | No | No |
| Confusion | Yes | Yes | No | Yes | No | No |
| Amnesia | Yes | Yes | No | Yes | No | No |
| Treatment for headache | Yes | No | No | Yes | No | No |
| Post-concussion symptom | 10 | 5 | 3 | 6 | - | - |
| Post-concussion RTP days | 14 | 21 | 7 | 10 | - | - |
| Time from concussion incident to data collection (days) | 263<br>216 | 118 | 267 | 462<br>297<br>162 | - | - |

Criteria of selection for the concussed group was positive concussion incidents in the past season (8 months prior to first data collection) with 7 to 21 days' RTP timeline. RTP decision was aided by subsequent ImPACT testing by clinicians of Grand Forks Public schools after the concussion. TABLE I shows the details of immediate status after concussion for each subject. The data were collected in three visits. Therefore, there was a total of 18 data collection trials. Time elapsed between concussion incident and data collection varied from 8 months to 1 year for three different visits. Visit 1 data were collected at 8 months, Visit 2 data were collected at 10 months, and Visit 3 data were collected at 12 months after the concussion. The time session was divided into three groups based on pre-season, mid-season, and post-season for a football season (fall semester) of Grand Forks area high schools. During this five month period of data collection, none of the subjects reported any further concussions.

### *B. Neurocognitive Data Collection Protocol:*

Assessment tools used for neurocognitive analysis were the ImPACT, BESS, and K-D tests. The choice of these tests was based on popularity and portability. Athletic trainers at the site of the game actively use these tests, even when those trainers have to travel long distances to those games [7-9].

*i)* ImPACT is a widely used scientifically authenticated computerized concussion assessment system as well as a medically accepted tool used by physicians for RTP decisions. Five composite scores were generated during ImPACT from six subtests. A symptom composite score was also reported, where athletes were asked 22 symptom checklist questions (e.g., headache, nausea, irritability), to rate the symptoms on a scale of 1 to 7 and a total Post Concussion Symptom Score (PCSS) was generated combining all of them [7].

*ii)* The K-D test is a two-minute rapid number naming assessment in which an individual reads numbers aloud quickly from test cards [8].

*iii)* For postural stability assessment, we used BESS. This study used a modified Wii Balance Board to record center of pressure during the performance of the BESS. Center of pressure data was collected for 20 seconds from each subject for three different tasks (double leg stance, single leg stance and tandem stance) on two separate surfaces (a firm surface and a foam surface) for a total of six different trials [9]. The error was calculated by summing balance errors from each trial.

### *C. EEG Data Collection Protocol:*

EEG data analysis was used for electrophysiological assessment since it is one of the most used tools to evaluate dysfunctions associated with brain signals. Advantages of EEG also includes its availability, effectiveness of analyzing these types of data and its noninvasive nature. Moreover, existing evidence indicates that EEG recordings can detect abnormal brain activities in asymptomatic concussed athletes, demonstrating superior sensitivity over neuropsychological assessments [6].

The data were collected for 5 minutes from each subject under vigilant task (VT), eyes open (EO), and eyes closed (EC) conditions. These were done to create high engagement, low engagement, and distraction status for both healthy and concussed subjects. Details of this protocol are shown in TABLE II. The same procedure was followed for all three visits.

EEG data were recorded by using a 9-lead wireless B-Alert headset. During data collection, the left earlobe was used as a reference and right earlobe was used as a ground. The sampling rate for data collection was 256Hz for all three conditions. Data were acquired by placing electrodes at Fz, F3, F4, Cz, C3, C4, Poz, P3, and P4 locations. The experimental setup is shown in Fig. 1.

### *D. Neurocognitive Data Analysis:*

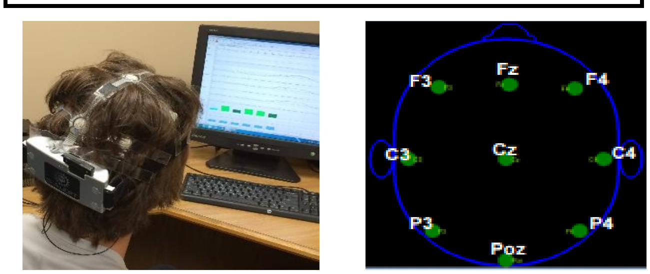
ImPACT data were analyzed from five composite scores called verbal memory score, visual memory score, processing speed score, reaction time score and impulse control score for both healthy and concussed athletes.

For the K-D test, total time required to complete the task was calculated for each healthy and concussed subject. Then average times for healthy and concussed athletes were compared to assess the performance.

The BESS test analysis was done by calculating the average x and y-axis sway (cm) in addition to the total number of balance errors for each healthy and concussed subjects to measure their postural performance.

TABLE II. EEG DATA COLLECTION TASKS

| Tasks | Action | Status |
|---|---|---|
| Vigilance Task | Choose between primary vs. secondary or tertiary task every 1.5 to 3 seconds. | High Engagement |
| Eyes Open | Respond to visual probe every 2 seconds. | Low Engagement |
| Eyes Closed | Respond to audio tone every 2 seconds. | Distraction |




(a) (b)

Figure 1. (a) Experimental setup for EEG data collection, (b) 9 Electrodes locations.

## E. EEG Data Analysis:

On artifact free data, the average log10 power spectral density (PSD) analysis was performed in the frequency range of 1-40 Hz. Next, absolute and relative power were computed for delta (1-3 Hz), theta (4-7 Hz), alpha (8-13 Hz), beta (14-30 Hz), and gamma (31-40 Hz) frequency bands.

# III. RESULTS

For the ImPACT assessment, an independent t-test analysis was performed on composite scores generated from the six subtests. The t-test revealed significant differences between healthy and concussed subjects in processing speed ($p = 0.042$) and impulse score (0.043), as shown in TABLE III. The significance level for the test was chosen to be 0.05.

TABLE III. IMPACT COMPOSITE SCORES

| Composite Scores | Healthy Athletes | Concussed Athletes | *p*-Value |
|---|---|---|---|
| Verbal Memory | 94.50 | 87.75 | 0.156 |
| Visual Memory | 89.00 | 81.25 | 0.090 |
| Processing Speed | 46.74 | 37.10 | **0.042*** |
| Reaction Time(ms) | 0.60 | 0.66 | 0.237 |
| Impulse Control | 1.00 | 6.00 | **0.043*** |
| Total Symptom Score | 2.50 | 8.75 | 0.212 |

In all three sessions of the K-D test, the concussed athletes required longer times compared to the healthy group, however, this difference in time was statistically insignificant.

The BESS test resulted in no statistical difference between healthy and concussed athletes performance in terms of average sway per second.

During EEG assessments, the concussed subjects showed an increase in delta and a decrease in beta and gamma frequencies in different regions of the brain (TABLE IV). Fig. 2 displays the deficits between the healthy and concussed athletes for EO, EC, and VT conditions during all three visits. Significance was tested using the independent sample t-test function at a significance level of 0.05.

TABLE IV. ELECTRODES WITH SIGNIFICANT DIFFERENCES

| Frequency Bands | Sensor Locations | | |
|---|---|---|---|
| | Visit 1 | Visit 2 | Visit 3 |
| Delta | Fz, F3, F4 | Fz, F3, F4 | Fz, F3 |
| Beta | Fz, F3, F4, C3, Cz, Poz, P3, P4 | Fz, F3, C3, Cz, Poz, P3, P4 | F3 |
| Gamma | F3, Cz, C3, Poz | F3, C3, Poz, P4 | F3 |

# IV. DISCUSSION

The ImPACT demonstrated reduced cognitive performance of concussed group in terms of processing speed and impulse control. While analyzing the individual performance of concussed athletes, it was found that these deficits mainly resulted due to the poor performance of two subjects from the concussed group who had multiple concussions within a short period of time. This outcome is consistent with the notion of [7], where a sample of rugby players with multiple concussion histories had a lower processing speed compared to a healthy control group.

K-D test did not reveal any visual processing deficits between the healthy and concussed athletes within the range of our data. Despite of our small dataset, the result supported the evidence of [8] that K-D test is mainly a rapid sideline tool to measure the immediate status after a concussion.

For the BESS, the comparison between previously concussed and non-concussed subjects resulted in insignificant differences. The performance of concussed athletes was very similar and even better (Visit 2) in terms of sway per second. Also, all the subjects exhibited nearly same number of average balance errors during all three visits. Due to lack of any significant deficits between the subjects in our dataset, our findings may be an indication of the well-known hypothesis along with [5, 6] that postural deficits are visible only during the acute phase of injury. Thus, after 8 to 12 months of concussion, BESS assessment is not adequate to find the substantial deficits between healthy and concussed athletes.

The EEG analysis showed residual deficits at certain

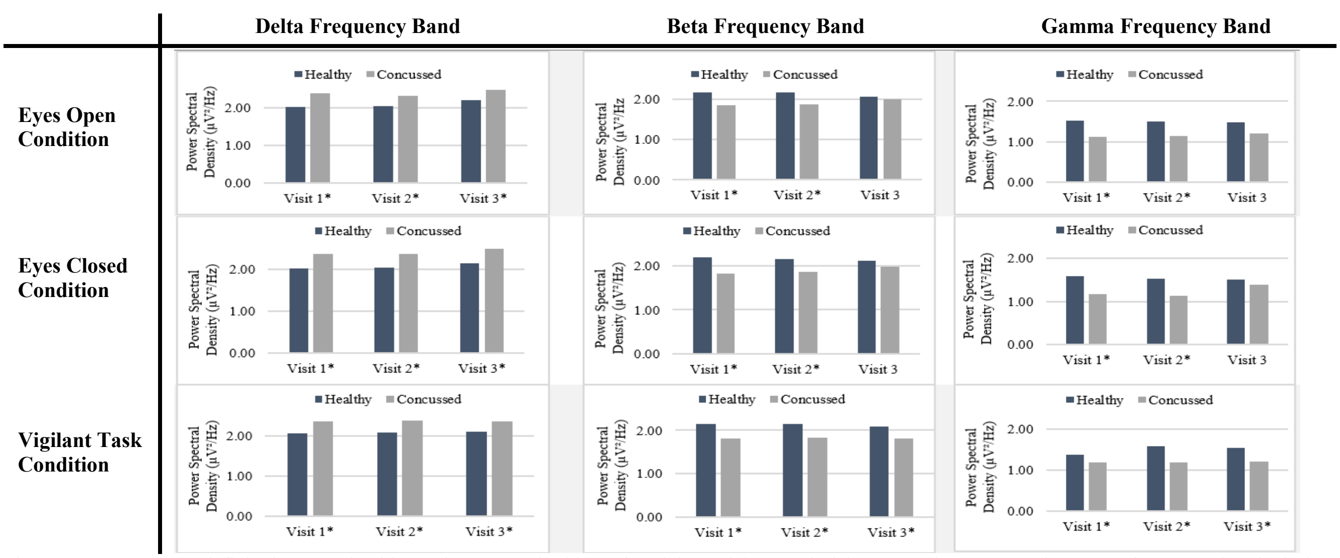



Figure 2. EEG power deficits between healthy and concussed athletes for visit 1, visit 2, and visit 3 at Delta, Beta, and Gamma frequency bands during Eyes open, Eyes Closed, and Vigilant Task conditions. * indicates significant difference with respect to healthy group ($p < 0.05$).

channels among the athletes, along with the trend showing the change of deficits over time for three different visits. The concussed athletes showed an increase in delta frequency band mainly at the frontal region of the brain for all three visits. According to [10], an increase in delta frequency band may indicate brain injuries, learning problems, or inability to think and Attention Deficit Hyperactivity Disorder (ADHD). There was a significant decrease in the Beta and Gamma frequency bands in all three regions (frontal, central, and parietal) of the brain at visit 1 and 2 and frontal region during visit 3 for concussed athletes. Certain levels of Beta waves allow easy focus and involvement in conscious thought and logical thinking, whereas a decrease in beta waves may point to poor cognition [10]. Gamma frequency is mainly involved in cognitive functioning as well as higher processing tasks; previous studies showed that mentally challenged individuals and individuals who have learning disabilities tend to exhibit lower gamma frequency than average [10]. Therefore, the decrease in beta and gamma frequency for concussed athletes compared to healthy athletes is an indicator that the concussed athletes are not as electro-physiologically sound as healthy athletes.

The observation from 3 samples of EEG data suggested that the alteration in brain signal was most prevalent during visit 1, which may be because of the low time difference between concussion incident and data collection. With increased time gap during visit 2 and visit 3, some of the difference between concussed and healthy subjects disappeared. Thus, our findings are in accordance with the well-known concept of many current studies like [5] and [6] which showed that alteration in brain signals of a concussed person dissipates over time. Moreover, the findings of an increase in delta and decrease in beta are in line with the findings of [11]. Also, among these three conditions, we found VT to be more sensitive to exhibit brain signal alterations, this is due to its nature which requires high brain engagement. Visit 3 results showed alteration mainly in frontal region of the brain. This leads us to conclude that frontal region of the brain required a longer time to overcome the effect of concussion in comparison to the other areas of the brain.

If we examine the electrode positions which revealed the deficits in electrophysiological assessment, it is found that the alteration was mainly at the Fz, F3, and F4 electrodes of the frontal region and the P3 and P4 electrodes of the parietal region of the brain. Fz, F3, and F4 electrodes mainly deal with the working memory (Fz) and motor planning (F3 and F4) capability of the brain whereas the P3 and P4 region define the cognitive processing ability, like verbal reasoning (P3) and nonverbal reasoning (P4) [10]. These deficits were exhibited through EEG test, without showing any deficits during BESS and K-D tests. As indicated in [12], it can be described by the principle that concussed athletes recruit additional brain resources to compensate and achieve normal postural functioning; thus, an alteration is found in brain signals, though their physical performance is similar to healthy subjects. Therefore, we believe EEG would be more sensitive towards detection of concussion and its enduring influence.

## V. Conclusion

Accumulated evidence from this preliminary study suggested there may be a residual detrimental cognitive and electrophysiological effect of past concussion history. Also, the findings cross-validate the efficacy of some widely used neurocognitive and electrophysiological concussion assessment tools. Thus, the current preliminary study highlights towards a potential application in concussion management by providing evidence to identify the athletes who are at risk for sustaining physiological deficits and thus can play a significant role in RTP decision also.

Although the current study yields some promising results it has a limitation of a smaller sample size. To generalize our findings further analysis with a bigger sample size of two groups would be required.

## Acknowledgment

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