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Feasibility of EEG Measures in Conjunction With Light Exercise for Return-to-Play Evaluation After Sports-Related Concussion

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Abstract

Current clinical assessment of sports-related concussion and the determination of ‘Return-to-Play’ lacks assessment of the pathophysiological processes affecting the concussed brain. The objective of this study was to demonstrate the feasibility of EEG measures which detect neuronal damage and monitor the healing process, giving an improved approximation of pathophysiological recovery.

Keywords

EEG; mild traumatic brain injury; YMCA Bike protocol; Return-to-Play

1. Introduction

Research into sports related concussion (SRC) or mild traumatic brain injury (mTBI) has increased significantly. Concurrently, our understanding of the pathophysiological response to injury in the brain has expanded tremendously over the past decade. Given the high rates of sports-related brain injury (Lincoln, 2011), our advanced knowledge of its complex pathophysiology (Giza, 2001; Barkhoudarian, 2011), and the documented short and long term physical and mental health issues associated with concussion (Teasdale, 2001; Uryu, 2002; Blaylock, 2011), it remains unclear why the clinical community has not adapted its clinical evaluation to include both functional/behavioral *and* physiological data points.

One possibility for the clinical discrepancy is that recovery from concussion is not currently defined in terms of pathophysiologic processes but in terms of self-reported symptoms and cognitive performance. Thus “recovery” from concussion is determined by the resolution of “clinical symptoms” and “functional disturbances”. However, without the inclusion of modalities measuring underlying pathophysiological processes affecting the brain, assessment of recovery from concussion remains incomplete. Fortunately, there are modalities which can provide the clinician with useful physiological measurements.

One such modality is electroencephalography (EEG). The advancement of EEG has given clinicians a modality to measure and quantify residual pathology (Arciniegas, 2011). Within

the mTBI literature, EEG has measured alterations in power dynamics across electrical spectra in cohorts complaining of post-concussive symptoms (Arciniegas, 2011). Moreover, EEG has been combined with other clinical measures to detect residual abnormalities not realized in behavioral data (Gosselin, 2006; Broglio, 2009; Jaiswal, 2009; Slobounov, 2009; Thériault, 2009; McCrea, 2010). Therefore EEG offers the potential to track physiologic information throughout all stages of recovery from sports-related concussion. However, to date, no studies investigating EEG and exercise in a mTBI cohort have been conducted.

The specific aim of this study was to measure the effects of exercise on neural correlates (EEG absolute power) in clinically ‘asymptomatic’ subjects recovering from concussion and initiating the ‘Return-to-Play’ protocol compared to neurologically normal volunteers (NV).

2. Methods

2.1. Study Participants

All subjects were college aged student-athletes participating in organized sports (N = 18). NV (N=9) being used as age-matched controls had no history of mTBI and were neurologically intact with no history of mental/mood disorder. Each athlete in the mTBI group (N=9) was previously diagnosed with a concussion by a certified athletic trainer and physician trained in the management of sports related concussion. All mTBI subjects met the criterion for ‘asymptomatic’ and had thus been cleared for the ‘Return-to-Play’ protocol (McCrory, 2005) by their supervising physician.

2.2. EEG System

Net station 1.3 (Geodesic Systems Inc, Eugene OR, USA.) software was used to record the real time tracings from the 128-lead HydroCel Geodesic Sensor array. The EEG signal passed through the Net Amps 300, a high-input impedance amplifier. Standard filtering was used during the recording of EEG signals (Low Pass Filter 70 Hz, High Pass Filter .3 Hz, and Notch filter 60Hz).

2.3. Experimental Protocol

(a) EEG Application—Subjects were fitted with the EEG sensor array with Cz being positioned over the frontal/sagittal intersection lines drawn at the top of the cranium. Electrode distribution conformed to the 10-5 system of electrode placement (Oostenveld, 2001).

(b) Bike Protocol—The YMCA bike protocol starts with an accommodation period of about 2 min on a cycle ergometer. The accommodation period is followed by 4 separate stages of increasing exercise intensity lasting 3 minutes each. Heart rates were monitored using a Polar H4 Heart Transmitter with strap (Polar Electro Inc. Lake Success, NY). The YMCA bike protocol was modified when the subjects reached their age-adjusted 70% MHR by holding their resistance constant for the remaining duration of the protocol.

2.4. EEG recording and analysis

EEG recordings were taken with eyes closed under four conditions. Condition 1: Rest; Condition 2: Bike; Condition 3: Post-Bike and Condition 4: 24 hours Post-Bike.

The Net Station (Eugene, OR) waveform toolbox was used for all signal pre-processing procedures. The recordings were all sampled at 500 Hz and referenced to Cz. The pre-processed data files were exported and a specialized MATLAB (Mathworks Inc. Natick, MA; Version, 2012) code produced absolute power (frontal, central and posterior regions) measurements for each frequency distribution (Delta, Theta, Alpha and Beta)

3. Results

3.1. Physiological Data

The YMCA Bike protocol was capable of inducing comparable changes to each subjects' heart rate during the 4 stages of the bike test. There were no differences between the two groups' heart rates ($p > 0.05$). No subjects experienced any post-concussion symptoms before, during or after modified YMCA Bike protocol.

3.2. EEG Results

Statistical analysis revealed significant differences in whole brain Alpha ($f(12) = 5.79$; $p = 0.001$); Beta ($f(11) = 4.49$; $p = 0.004$); Delta ($f(8) = 4.95$; $p = 0.002$); and Theta ($f(10) = 7.36$; $p = 0.000$) power means between groups across two conditions (Bike, 30 min Post-Bike). Regional Alpha, Beta, Delta and Theta absolute power mean differences between groups are illustrated in Figure 1.1.

4. Discussion

4.1 Clinical Findings

First, the YMCA bike protocol was capable of producing similar physiologic changes in all subjects and there were no group differences in dynamic measures of heart rate. In addition, both groups reported no presentation of symptoms related to concussion and all subjects were able to finish the exercise protocol. The absence of post-concussive symptoms with exercise allows the athlete to progress in stages of the 'Return-to-Play' protocol (McCrory, 2005).

4.2 EEG Findings

First, there were no differences between groups under normal resting conditions in EEG measures of absolute power (Condition 1 and 4). Second, the YMCA Bike protocol significantly increased alpha, beta, theta and delta absolute power across all regions (frontal, central and posterior) in the mTBI group compared to NV.

In this study we confirmed that light exercise increased Alpha, Beta, Delta and Theta power in both cohorts. These findings are consistent with the findings of both Schneider (2009, 2010) and Crabbe (2004) who found increases in the absolute power in the period of time following exercise. However, mTBI subjects demonstrated significantly higher absolute

power within Alpha, Delta and Theta frequency bands during the Bike (Condition 2) and all frequency bands at 30 min Post-Bike (Condition 3) compared to normal volunteers. Of clinical importance was the presence of significant increases in Theta and Delta frequency absolute power. Theta power increases potentially stem from injury and pathophysiologic changes in the cerebral cortex (Montgomery, 1991). In work by Nagata, his group demonstrated that cortical blood flow (CBF) and oxygen (O₂) metabolism correlated negatively with Delta and Theta power (Nagata, 1990). In addition, increases in Theta power have long been established in the mTBI literature (McClelland, 1994; Fenton, 1996) and are indicative of pathology. Additionally, Delta activity has been known to increase in many pathological states (Bates, 2009; Babiloni, 2009; Korb, 2008).

5. Conclusions

Measurement of physiological biomarkers of injury from concussion are critical to the clinician making safe 'Return-to-Play' determinations. This study demonstrates that the incorporation of EEG as a clinical modality during light exercise in the 'Return-to-Play' protocol following recovery from sports related concussion is feasible. Furthermore exercise used in this study was capable of enhancing residual abnormalities on EEG measures that were not otherwise observable at rest.

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Highlights

- Clinical symptoms resolve shortly after concussion
- Clinical symptoms resolution may not reflect restoration of pathophysiology
- EEG may complement clinical tools to assess the prognosis of concussion

Figure 1.1.

Regional Brain Absolute Power Means between Groups across Conditions:

Alpha- Means were significant for frontal alpha ($p = 0.012$) power between groups under Condition 2. Central alpha ($p = 0.001$) and posterior alpha ($p = 0.005$) power were significant under Condition 3. **Beta**- Means were significant for central beta ($p = 0.007$) and posterior beta ($p = 0.013$) power between groups under Condition 3. **Delta** - Means were significant for frontal delta ($p = 0.001$), central delta ($p = 0.001$) and posterior delta ($p = 0.000$) power between groups under Condition 2. Central delta ($p = 0.008$) and posterior delta ($p = 0.005$) power were significant under Condition 3. **Theta** - Means were significant for frontal theta ($p = 0.002$), central theta ($p = 0.001$) and posterior theta ($p = 0.000$) power between groups under Condition 2. Central theta ($p = 0.001$) and posterior theta ($p = 0.000$) power were significant under Condition 3.