Cumulative soccer heading amplifies the effects of brain activity observed during concurrent moderate exercise and continuous performance task in female youth soccer players

Alexandra Harriss¹, Andrew M Johnson¹,², James W G Thompson³, David M Walton¹,²,⁴ and James P Dickey⁵

Abstract

Objectives: To determine whether youth female soccer players demonstrate spectral changes in electroencephalogram activity during a continuous performance test, related to cumulative soccer heading at rest and during exercise.

Setting: Community soccer facilities.

Participants: Twenty-four female youth soccer players (age: 13.1 ± 0.8 years, mass: 49.5 ± 8.6 kg, height: 1.6 ± 0.1 m).

Methods: Players completed testing at four time points during the soccer season. The continuous performance test involved players responding to target stimuli or refraining from responding to non-target stimuli. Omission errors (player failed to respond to target stimuli) and commission errors (player responded to non-target stimuli) were assessed for each continuous performance test. Electroencephalogram frequency bandwidths were divided into Theta (4.0–7.9 Hz), Alpha1 (8.0–9.9 Hz), Alpha2 (10.0–12.9 Hz), Beta1 (13.0–17.9 Hz), and Beta2 (18.0–29.9 Hz). Linear mixed-effects modeling was performed on electroencephalogram power at electrode locations Fp1, Fp2, F3, F4, F7, F8, C3, and C4. Participants completed a continuous performance test during rest and moderate exercise.

Results: Omission errors significantly increased during exercise compared to rest at all time points (p < 0.05), but not commission errors. Linear mixed-effects models revealed that there was a statistically significant increase in electroencephalogram power during exercise across all frequency bands (p < 0.05); the number of cumulative headers amplified this difference for Alpha1, Alpha2, and Beta2 (p < 0.05). There were no statistically significant differences between cumulative number of headers and remaining electroencephalogram frequency bands (all p values > 0.05).

Conclusion: Moderate exercise may help to elicit sub-clinical changes in youth female soccer players due to cumulative head impacts, which are not apparent at rest.

Keywords
Adolescent, concussion, head impacts, brain injury, repetitive, girls

Introduction

Most soccer-related head injuries occur from contact with other players¹; however, soccer players routinely experience head impacts through purposely heading the ball. Purposeful soccer heading occurs when players deliberately use their head to direct the soccer ball. There is concern that cumulative head impacts through purposeful soccer heading may influence neurological
functioning. For example, some studies show that repetitive head impacts, such as purposeful soccer heading, do not lead to immediate changes in neuropsychological testing or advanced neuroimaging, while other investigations report adverse sequela. Using diffusion-tensor imaging, one group reported that the number of headers a soccer player performed within the last year was associated with the degree of axonal injury for specific regions of interest. Another study revealed that elite male soccer players show evidence of increased radial and axial diffusivity in areas of the brain including the corpus callosum, over the course of a normal season. Similar neuroimaging findings have also been reported in American football players who experience repetitive head impacts. Collectively, these findings indicate that cumulative head impacts may cause impairments in areas of the brain that are not explained by a history of a diagnosed concussion.

Electroencephalogram (EEG) recordings reveal abnormal brain functioning in people diagnosed with a concussion, yet they can have normal clinical concussion test scores. Similarly, EEG abnormalities are shown in people diagnosed with a concussion while performing virtual reality balance and spatial tasks. Taken together, these findings suggest that some type of compensatory brain mechanism is occurring to achieve what appears to be normal functioning. A continuous performance test (CPT) presents patients with stimuli that require them to respond to target stimuli or refrain from responding to non-target stimuli. Omission errors result when the participant fails to respond to target stimuli, whereas commission errors result when the participant responds to non-target stimuli. Omission and commission errors during CPTs provide valuable information regarding inattention and impulsivity, respectively.

The cumulative effects of purposeful soccer heading may demonstrate EEG abnormalities that are currently reported in patients diagnosed with a concussion in that participants can successfully perform a CPT by engaging additional brain resources to compensate for the injured brain areas. It is expected that these abnormalities will become amplified with additional effort, such as moderate exercise, making neurological deficits more readily identifiable.

Heading is a frequent part of youth soccer, yet this population is understudied. The youth age period is a sensitive time for the developing brain, potentially rendering this group more vulnerable to the negative effects of purposeful heading. Still, it is not known whether purposeful heading can lead to abnormal brain activity during or after a single soccer season. Accordingly, the purpose of this study was to explore the relationship between cumulative purposeful soccer heading and electrophysiological brain functioning during a single season of female youth soccer. We examined female youth soccer players as they have a higher risk of concussion. This study employed spectral analysis of EEG to determine whether youth female soccer players demonstrate spectral changes in EEG activity at electrode locations Fp1, Fp2, F3, F4, F7, F8, C3, and C4 at rest and during moderate exercise, while participants completed a CPT. Previous studies show increases in brain activity as a result of exercise. Accordingly, our hypothesis was that exercise would result in increased EEG activity for each frequency band across all electrode sites compared to rest. In addition, we hypothesized that these differences between rest and exercise would be amplified as players experience a greater number of cumulative purposeful headers.

Methods

Participants

Twenty-four elite female soccer players from three different youth age groups (under 13, under 14, and under 15) were recruited for this study. All players were part of the Ontario Player Development League and competed in 20 regular season games during a six-month period. Participants were excluded if they were diagnosed with a concussion during the season or within the previous six months, or if they had a diagnosed learning disability or any neurological or psychiatric disorders. Participant assent and parent consent were obtained prior to participation. This study protocol was approved by the Health Sciences Research Ethics Board at the University of Western Ontario (HSREB# 107948).

Electroencephalogram recordings

In accordance with the International 10–20 system, 22 electrodes were positioned on the participant’s scalp using a spandex EEG recording cap (Electro-Cap. Eaton, OH, USA: Electro-Cap, International). Nineteen scalp locations were recorded, and all leads used linked ears as reference, and AFz as the ground. Impedances at all recording sites were below 10 kΩ. Electroencephalogram recordings were 20 min in duration (10 min resting and 10 min moderate exercise) and completed using the eVox system (Evoke Neuroscience, Inc., New York, NY). The system bandwidth defined by post-processing filters was 1–30 Hz, and the sampling frequency was 250 Hz. Since the antialiasing filter only attenuated the signals to 20% at 60 Hz (Smith 1997), a 60 Hz notch filter was employed to further attenuate any potential signal from power mains.
Data were recorded to a Dell Latitude E6440 laptop running an i7 processor.

EEG frequencies were divided into the following bands: Theta (4.0–7.9 Hz), Alpha1 (8.0–9.9 Hz), Alpha2 (10.0–12.9 Hz), Beta1 (13.0–17.9 Hz), and Beta2 (18.0–29.9 Hz). Female soccer players experience the majority of purposeful soccer headers on the front and top of the head. Accordingly, we assessed power for each frequency band at electrode sites at the frontal (Fp1 & Fp2), mid-frontal (F3 & F4), lateral-frontal (F7 & F8), and central (C3 & C4) locations, as these electrodes are preferentially influenced by neural activity close to these regions, though also affected by neural activity from more distant areas due to volume conduction. Temporal electrode sites were not assessed due to excessive contamination with artifact from masseter muscle activation.

Off-line analysis was performed using Evoke Neuroscience’s Report Generator software. Artifact removal and data filtering were specifically tuned for the exercise condition and were used to process the resting conditions as well. Data were manually inspected and segments that contained movement artifacts or excessive muscle activity at any electrode site were eliminated from further analyses. Independent component analysis was used to detect and correct eye blinks in order to improve signal quality.

**Experimental protocol**

Video from each of the 20 matches was recorded using a Sony Vixia HD camera mounted to a telescoping tower (EVS25, Endzone Video Systems, Sealy, TX, USA). The game video was analyzed using a video analysis software tool (dba HUDL, Agile Sports Technologies Inc., Lincoln, NE, USA), and the number of headers was recorded by one researcher for all games. Previous research has determined that one rater is sufficient to reliably record the number of purposeful soccer headers.

Participants avoided caffeine and high intensity physical activity on each of the testing days. EEG testing was conducted at four time points during the soccer season: baseline, two mid-seasons, and a post-season measure. At baseline, anthropometric data and concussion history were collected. Participant EEG was recorded at two conditions, rest and during moderate exercise. During each condition participants completed a CPT, whereby either target (big circle) or non-target (small circle) stimuli were presented on a computer monitor at defined time intervals and the participants responded. The participants were instructed to press a button as quickly as possible when presented with the target stimuli and refrained from responding to non-target stimuli.

For the moderate exercise condition, a cycle ergometer was used to limit movement artifact. Preferred seat height and handle bar position was consistent across sessions. Participants selected a cycling cadence that they could maintain throughout the entire ten minutes. Biking intensity increased each minute throughout the test, based on participant mass and revolutions per minute, similarly to other concussion exercise protocols. The Borg rating of perceived exertion (RPE) scale was used at the start and end of the rest and exercise condition. This scale is a simple numeric list and participants verbally reported a number between 6 (no exertion at all) to 20 (maximal exertion) corresponding to their perceived exertion. Participants rested for up to ten minutes between conditions.

**Data analysis**

The mean and range are reported for the number of cumulative purposeful headers at each testing time point. Descriptive statistics for participant demographics and RPE during each condition (rest and exercise) are reported as means and standard deviations. In order to ensure that the effects of sustained exercise were present, we chose to analyze the second half of both the exercise and rest conditions and treated the initial 5 min as warm-up periods.

Commission and omission errors are reported as median and range as they were not normally distributed. A Wilcoxon signed-rank test was used to determine the statistical significance of the differences in commission errors between rest and exercise. The same analysis was used for omission errors. These analyses were carried out in IBM SPSS Statistics (version 25). A p-value of <0.05 was considered statistically significant.

The EEG signals were digitized using a separate 24-bit analog-to-digital converter for each channel. Power for Theta, Alpha1, Alpha2, Beta1, and Beta2 were considered as dependent variables. A linear mixed-effects model evaluated whether the main effects of testing time, experimental condition (rest, exercise), and electrode site (Fp1, Fp2, F3, F4, F7, F8, C3, C4) predicted EEG power for each dependent variable. Testing time, experimental condition, and electrode site were entered as fixed effects to determine whether the main effects model predicted EEG power for each dependent variable. This main effects model was tested against a null model consisting of only subject variance. Cumulative number of headers was then entered into the main effects model as a random effect, and this revised model was tested against the original main effects model to determine whether or not accounting for the cumulative number of headers significantly improved the prediction. The interaction (condition by site) was
then tested against the main effects model that included cumulative headers. A p-value < 0.05 was considered significant.

Results

One player sustained a concussion during the soccer season and was excluded from analysis. The mean age of the remaining 23 participants was 13.1 (SD: 0.8) years old, with a mass of 49.5 (SD: 8.6) kg and height of 1.6 (SD: 0.1) m. The average cumulative number of purposeful headers at follow-up was 6.4 (range: 0–29), 15.4 (range: 1–49), and 23.5 (range: 6–61) at follow-ups one, two, and post-season, respectively.

Continuous performance test

At each testing session, all players successfully completed the rest and exercise conditions. Overall, average RPE difference before (6.55 SD: 1.02), and after (6.86 SD: 1.75) the rest condition was not statistically significant (p = 0.34). During exercise, participants cycled at 57.30 (SD: 6.31) r/min. RPE statistically significantly increased throughout the exercise condition (before 6.59 SD: 1.30, after 15.7 SD: 1.7). Median errors for omission and commission scores are presented in Table 1. There was a statistically significant difference between rest and exercise omission scores, in that omission scores increased during exercise compared to rest omission scores, in that omission scores were entered as a random effect, the main effects model was statistically significantly improved at predicting EEG power (χ² (1) = 84.36, p < 0.0001). The interaction model (condition by site) was significantly better at predicting these data compared to the main effects model (χ² (7) = 56.09, p < 0.0001). Exercise caused EEG power to increase compared to the rest condition (Figure 1).

Specifically, a statistically significant difference in EEG power between rest and exercise was demonstrated at the frontal electrode sites (Fp1: 0.15 μV² SE 0.02, t(1205) = 7.29, p < 0.0001; Fp2: 0.14 μV² SE 0.02, t(1205) = 6.43, p < 0.0001; F3: 0.08 μV² SE 0.02, t(1205) = 3.9, p = 0.0001; F4: 0.07 μV² SE 0.02, t(1205) = 3.35, p = 0.008; F7: 0.14 μV² SE 0.02, t(1205) = 6.61, p < 0.001; F8: 0.14 μV² SE 0.02, t(1205) = 6.64, p < 0.001). There were no statistically significant differences at central electrode sites (C3: 0.03 μV², SE 0.02, t(1205) = 1.41, p = 0.16; C4: 0.01 μV², SE 0.02, t(1205) = 0.35, p = 0.72).

Alpha 1

Considering the Alpha 1 frequency band, the main effects model (experimental condition, site, and testing time) was significantly better at predicting EEG power compared to the null hypothesis (χ² (11) = 533.94, p < 0.0001). When cumulative headers were entered as a random effect, the main effects model was statistically significantly improved at predicting EEG power (χ² (1) = 84.36, p < 0.0001). The interaction model (condition by site) was significantly better at predicting these data compared to the main effects model (χ² (7) = 56.09, p < 0.0001). Exercise caused EEG power to increase compared to the rest condition (Figure 1).

There were no statistically significant differences at central electrode sites (C3: 0.03 μV², SE 0.02, t(1205) = 1.41, p = 0.16; C4: 0.01 μV², SE 0.02, t(1205) = 0.35, p = 0.72).

Alpha 2

Alpha 2 power demonstrated that the main effects model (experimental condition, site, and time) was significantly better at predicting the data than the null model (χ² (1) = 461.64, p < 0.0001). When cumulative headers were entered as a random effect, the main effects model was significantly better at predicting EEG power (χ² (1) = 29.09, p < 0.0001). The interaction model (condition by site) was significantly better at predicting EEG power than the main effects (χ² (7) = 33.81, p < 0.0001). Exercise caused EEG power to increase compared to the rest condition (Figure 2).

In particular, a statistically significant difference in EEG power between rest and exercise was demonstrated at the frontal electrode sites (Fp1: 0.11 μV², SE 0.02, t(1206) = 6.37, p < 0.0001; Fp2: 0.10 μV², SE 0.02, t(1206) = 5.86, p < 0.0001; F3: 0.08 μV² SE 0.02, t(1206) = 4.64, p < 0.0001; F4: 0.08 μV² SE 0.02, t(1206) = 4.26, p < 0.001; F7: 0.11 μV² SE 0.02, t(1206) = 2.86, p < 0.001; F8: 0.11 μV² SE 0.02, t(1206) = 2.86, p < 0.001).

Table 1. Continuous performance test for omission errors and commission errors.

| Condition          | Outcome measure | Baseline (median %, range) | Follow up 1 (median %, range) | Follow up 2 (median %, range) | Post season (median %, range) |
|--------------------|-----------------|----------------------------|-------------------------------|-------------------------------|-------------------------------|
| Rest (median %, range) | Omission      | 0.0 (0.0–8.57)             | 0.0 (0.0–11.43)               | 3.86 (0.0–11.43)              | 0.0 (0.0–48.57)               |
| Exercise (median %, range) | Omission     | 11.43 (0.0–54.29)          | 11.43 (0.0–34.29)             | 5.71 (0.0–40.0)               | 7.41 (0.0–45.71)              |
| Rest (median %, range) | Commission   | 1.63 (0.0–3.27)            | 0.41 (0.0–4.49)               | 0.0 (0.0–3.27)                | 0.41 (0.0–3.27)               |
| Exercise (median %, range) | Commission | 0.82 (0.0–4.90)            | 0.41 (0.0–7.76)               | 0.0 (0.0–4.90)                | 0.41 (0.0–2.04)               |
**Figure 1.** Interaction plot illustrating the spectral power in the Alpha1 band between electrode site and experiment condition (rest and exercise). The points indicate least square means and error bars represent standard error. Asterisk (*) represents statistically significant differences between rest and exercise ($p < 0.05$).

**Figure 2.** Interaction plot illustrating the spectral power in the Alpha2 band between electrode site and experiment condition (rest and exercise). The points indicate least square means and error bars represent standard error. Asterisk (*) represents statistically significant differences between rest and exercise ($p < 0.05$).
t(1206) = 6.12, p < 0.0001; F8: 0.11 μV², SE 0.02, t(1206) = 6.07, p < 0.0001). There were no statistically significant differences at central electrode sites (C3: 0.04 μV², SE 0.02, t(1206) = 1.93, p = 0.05; C4: 0.01 μV², SE 0.02, t(1206) = 0.52, p = 0.60).

**Beta1**

Considering the Beta1 power, the main effects (experimental condition, site, and time) were significantly better at predicting the data than the null hypothesis model (χ² (11) = 452.79, p < 0.0001). The main effects model was significantly better at predicting EEG power when cumulative number of headers were entered as a random effect (χ² (1) = 68.71, p < 0.0001). The interaction model (condition by site) was not better at predicting EEG power than the main effects (χ² (7) = 2.33, p = 0.93).

**Beta2**

Considering the Beta2 power, the main effects (experimental condition, site, and time) were significantly better at predicting the data than the null hypothesis model (χ² (11) = 199.25, p < 0.0001). When cumulative number of headers was entered into the model as a random effect, the main effects model was significantly better at predicting EEG power (χ² (1) = 130.91, p < 0.0001). The interaction model (condition by site) did not better predict EEG power than the main effects (χ² (7) = 13.77, p = 0.06).

**Theta**

The main effects model (experimental condition, site, and time) was statistically significant for Theta power (χ² (11) = 508.16, p < 0.0001). When cumulative number of headers was entered into the model as a random effect, the main effects model was significantly better at predicting EEG power (χ² (1) = 130.91, p < 0.0001). The interaction model (condition by site) did not better predict EEG power than the main effects (χ² (7) = 13.77, p = 0.06).

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**Figure 3.** Interaction plot illustrating the spectral power in the Beta2 band between electrode site and experiment condition (rest and exercise). The points indicate least square means and error bars represent standard error. Asterisk (*) represents statistically significant differences between rest and exercise (p < 0.05).
Discussion

This study evaluated changes in neurophysiological functioning at different times over the course of a female youth soccer season. Consistent with our hypothesis, EEG power during exercise increased at each frequency band compared to rest. As players experienced a greater number of cumulative purposeful headers, these differences in EEG power between conditions were amplified, but only for Alpha1 and Alpha2 power at all electrode locations, but C3 and C4 as well as Beta2 for all electrode locations, but Fp2 and F7.

Similar to previous work, our CPT outcome measures suggest normal functioning, while EEG recordings reveal that the exercise condition had increased Alpha as well as Beta2 power compared to rest. Notably, players that experienced a greater number of cumulative purposeful headers showed a statistically significant increase in Alpha and Beta2 when engaged in moderate exercise. Since the same effect was not seen at rest, these findings suggest that moderate exercise can amplify differences in cortical functioning and may serve as a more sensitive test of impairment in Alpha1, Alpha2, and Beta2 functioning. Although there were statistically significant main effects, none of the interaction models for the remaining frequency bands were better at predicting EEG power. Continuous performance task findings revealed a statistically significant increase in omission errors during exercise compared to rest. This is consistent with previous work, in that error rates increased with exercise intensity.27,28 We did not observe any statistically significant changes in commission errors between conditions, suggesting no impulsivity or hyperactivity behaviors during the CPT.

Previous work has used exercise to evaluate concussion injury as well as recovery.12–14 However, we are unaware of any studies that have examined the effects of cumulative header impacts on brain function when measured during moderate exercise. Previous work has shown that EEG activity appears to increase during and after exercise in healthy people.18 Our findings revealed statistically significant increases in Alpha1, Alpha2, and Beta2 power between rest and exercise. This difference was amplified when cumulative purposeful headers were incorporated into the model as a covariate. The impact of brain injury on alpha power has received much attention due to its possible association with several brain processes, such as its inhibitory control mechanisms.29 Following mild traumatic brain injury (mTBI), one study showed alpha power suppression during balance tasks pre- and post-mTBI injury.30 Other work has shown neurophysiological abnormalities in concussed athletes compared to controls including decreased whole brain beta and theta power during EEG baseline testing, as well as reductions in frontal beta power during ImPACT testing that achieved a similar level of performance on clinical tests.10 These findings suggest that patients with mTBI injuries utilize compensatory neural processes—adaptive strategies and altered brain resources to successfully perform required tasks. It is possible that our findings indicate such compensatory mechanisms.

In collegiate soccer players, there is accumulating evidence indicating a possible association between repetitive head impacts and abnormal changes in neural functioning.51 and structure.32 However, in youth soccer players, findings from neuropsychological testing batteries have not observed neurocognitive impairment immediately following soccer heading,3 a weekend soccer tournament,2 or one month of soccer participation.33 The lack of findings for neuropsychological testing has been purported to be due to compensatory processes that allow for normal overt behavior function in spite of altered neurological processes. Our findings show that cumulative purposeful soccer heading may be associated with negative changes in neurophysiological function and processes, in female youth soccer players, as indicated by increased alpha power. The novel aspect of this study is that we have demonstrated that measures of EEG power during exercise have the potential to inform researchers and clinicians, such as physiotherapists, of possible cognitive deficits, even at the subclinical level. This information may help provide the opportunity for early intervention remediation for individuals that do not show clinical symptoms.

There are some limitations to our study that should be considered. This study only recorded purposeful soccer headers during games and did not consider practices or non-header impacts (such as head to ground). Purposeful soccer heading has become a health concern,5 particularly for youth players.34 In addition, we only evaluated female youth soccer players. Youth male soccer players perform a greater number of headers compared to youth female soccer players during games35 and practices.36 Still, female youth soccer players experience a greater number of concussions as well as larger peak linear and rotational header accelerations compared to males.37 Our study only reported omission and commission errors. We did not report reaction time as it can be challenging when working with special populations.27 We only reported EEG from anterior sites due to their role in early deployment of cognitive processes, specifically the top-down processes.38 Recent imaging work also reveals abnormal findings in the anterior region of the brain related to soccer heading such as frontal temporal atrophy.32 However, this study did not assess temporal electrode
sites such as T3, T4, T5, and T6 due to contamination from masseter muscle activation, particularly during exercise. Accordingly, it is not known whether EEG activity would show meaningful differences in the temporal region, as well as other locations of the brain, such as the posterior region.

While the majority of studies evaluating cumulative soccer heading assessed participants at rest, we explored the effects of cumulative soccer heading during moderate exercise. Omission and commission errors obtained during the CPT reveal that participants at rest are able to achieve normal clinical testing scores; however, increasing task complexity (exercise) reveals statistically significant increases in omission error scores. In addition, EEG recordings show that moderate exercise leads to significant increases in alpha activity compared to rest and that cumulative number of headers amplified this difference. This suggests that players that experience a greater number of cumulative headers throughout the season produce increased alpha power during exercise. We believe that this increased alpha power reflects a compensatory mechanism in that by engaging additional brain resources, participants can successfully perform a CPT.

Conclusions
The implications of cumulative soccer heading on brain function in youth soccer players are unknown and understudied. Our findings show that neuropsychological outcome measures (such as omission and commission errors) may show normal cognitive functioning, but that EEG recordings during moderate exercise show sub-clinical neurocognitive dysfunction related to cumulative soccer heading. This study evaluated female youth soccer players for one season of play, and it is not known whether males, or other ages, or duration of study, or soccer calibers, will show similar findings. While omission and commission error scores were within normal clinical scores, measuring EEG recordings during exercise may reveal sub-clinical impairments resulting from cumulative soccer heading.

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ORCID iD
Alexandra Harriss https://orcid.org/0000-0002-9487-5603

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