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A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

QEEG POST-EFFECTS AFTER THE COMPETITION IN PROFESSIONAL FEMALE SOCCER PLAYERS

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SUMMARY

Background: Brain central fatigue has been hypothesized as a factor affecting sports performance that generally occurs after a competition. Therefore, the aim of this study was to observe brain activities after participating in a competition. This study used quantitative electroencephalography (QEEG) to evaluate brain central fatigue, and the results were analyzed in terms of brain connectivity (coherence) in the delta frequency bands.

Material/ Methods: QEEGs were recorded from twenty-nine Thai professional female soccer players (mean age ± SD was 24.17 ± 2.633 years, mean height ± SD was 1.620 ± 5.552 meters, mean weight ± SD was 55.10 ± 5.853 kg). We recorded QEEG three times: twice before a competition (once a week) and one week after the competition. Data obtained were analyzed by using the Z-scored FFT method. The results of brain connectivity were represented in terms of coherence.

Results: The present study revealed brain central fatigue in athletes after the competition (p=.035 and p=.003). This condition could affect their performance during games. Moreover, the average performance scores in the key players showed a significant difference from substitute players (p<.000). This confirmed that there was a distinction of brain activity. The brain commonly returns to a normal state after a competition. This phenomenon was observed in the substitute players. Contrastingly, key players (on the ground players) exhibited the brain central fatigue phenomenon

Conclusions: Our study confirmed that brain central fatigue can arise after a competition, and specific brain patterns can identify the level of sports performance. These findings are beneficial for predicting athletes' performances in terms of aspects of the brain. This approach can be used to measure and interpret brain central fatigue conditions.

Keywords: Quantitative electroencephalography (QEEG), brain connectivity (coherence), fatigue, brain central fatigue, delta frequency band, neuroergonomics

BACKGROUND

Soccer is a complicated sport that involves many activities such as tackling, jumping, lateral movements, and changing speed. Therefore, soccer induces great strain on several neuromuscular and metabolic parameters (Bangsbo 1994). In competition, critical points of the game often occur immediately after short-term intense periods (temporary fatigue), especially during the initial phase of the second half and towards the end of the game. Therefore, the physiological mechanisms must be able to maintain homeostasis when fatigue appears during different periods of a match. Temporary fatigue may contribute to muscle ion homeostasis disturbances (Mohr et al. 2005). Consequently, the magnitude of soccer match-induced fatigue, extrinsic factors (i.e., the match result, quality of the opponent, match location, playing surface) and/or intrinsic factors (i.e., training status, age, gender, and muscle fiber typology) can potentially influence the recovery period (Nedelec et al. 2012).

Neuroergonomics is the study of brain and behavior functions. It focuses on investigations of neural activities including perception and cognition such as seeing, hearing, attention, memory recall, decision-making, and planning which are associated with technologies and settings in the real world (Parasuraman 2003). Generally, traditional ergonomic evaluations have focused on the human body, such as quantifying muscle fatigue limited to peripheral biomechanical control and physiological responses. An interesting topic is whether the brain can also experience fatigue. The definition of mental fatigue (central nervous system fatigue or brain central fatigue) is a type of fatigue caused by functional changes within the central nervous system that are not associated with the muscular system. In addition, brain central fatigue refers to the effect of prolonged periods of cognitive activities (Davis and Bailey 1997). A growing number of muscle fatigue investigations have come to a consensus that central fatigue is related to the critical reduction in prefrontal oxygenation that accompanies muscular impairment during periods of exhaustion (Bhambhani et al. 2007 and Nybo and Rasmussen 2007) and (Thomas and Stephane 2008). In 2014, Mehta and Parasuraman used a neuroergonomic approach in a prefrontal cortex activation evaluation to qualify the association of mental and physical fatigue. The result of this study suggested interference in the prefrontal cortex that might influence on motor output. Therefore, when performing a task, the processing of both cognitive and physical functions is required. In addition, when an exercise is finished, activation of the prefrontal cortex (PFC) changes might contribute to a reduction in motor output.

Electroencephalography (EEG) is a recommended and sensitive approach for evaluating changes in neuronal activity. Due to the variations in mental activity that occur while an individual engages in a task and the changeable overall state of fatigue and alertness, neural activity can be detected (Parasuraman and Rizzo 2007). The differentiation of spontaneous EEG variables was previously evaluated according to types of mental fatigue (Tanaka et al. 2012). Nielsen et al. (2001) hypothesized that prolonged exercise in high temperature heat induces hyperthermia, which could result in brain fatigue. This also corresponded with alterations in frontal cortical brain activity, in which there was an accompanied shift in the EEG power distribution; when β decreased, there was a steady increase in the α/β index. Thus, a gradual slowing of EEG signals is related to exercise-induced hyperthermia. The increasing brain temperature causes a rise in central fatigue. This idea was demonstrated by changes in EEG, which reflect cerebral alterations (Rasmussen et al. 2004). Moreover, mental fatigue was studied in terms of event-related potentials (ERPs). A previous study evaluated the effects of mental fatigue on attention. The results demonstrated that fatigued subjects had decreased performance efficiency in a subjective fatigue rating. Increasing theta and lower-alpha EEG band powers also indicated increased fatigue. These results were characterized in fatigued people who had less flexibility and more distractibility (Boksem 2005). Furthermore, ERP activities could illustrate mental fatigue in terms of inhibition and execution responses, by which slower responses of inhibition were increased and execution responses were decreased. Thus, these results suggest that mental fatigue could be one factor that interferes with cognitive processing (Kato et al. 2009). The study of 2009, Lorist et al. evaluated neural dynamic activity during the performance of task switching by using EEG coherence. They examined the effects of individual motivation and mental fatigue on neural networks. The results showed variations in power and coherence due to mental fatigue. Additionally, recovery is one of the most important biological phases required by athletes. Empirical evidence has demonstrated that fatigue is primarily related to increases in the EEG delta frequency band (Knyazev 2012).

Therefore, the purpose of this study was to evaluate the effects of competition on brain central fatigue in Thai professional female soccer players. These events were described by brain connectivity (coherence), which involves exhaustion, relaxation, languidness, inertness, slowness, recovery, and mental fatigue. Interestingly, this phenomenon was associated with the brain patterns of athletes who exhibited high performance during the competition.

MATERIALS AND METHODS

Subjects and ethical issues

This study collaborated with the Sport Authority of Thailand (SAT), and the eligible subjects were Thai professional female soccer players who were attending in the 2014 AFC Women's Asian Cup. Twenty-nine eligible subjects were recruited (mean age ± SD was 24.17 ± 2.633 years, mean height ± SD was 1.620 ± 5.552 meters, mean weight ± SD was 55.10 ± 5.853 kg). There were three goalkeepers (GK), ten central defenders (DC) and full backs (DL/DR), nine defensive central midfielders (DMC) and central midfielders (MC), and seven forwards (FC) and strikers (ST). Twenty-six subjects were right-leg and -hand dominant and another three subjects were left-leg and -hand dominant.

All the subjects were asked to sign an informed consent after the study protocol was explained, which was approved by the Center of Ethical Reinforcement for Human Research, Mahidol University (COA No. MU-CIRB 2015/143.2411). The collected data were treated confidentially.

Eligibility criteria were professional female soccer players aged between 19 to 29 years old who had been involved in playing soccer for at least 3 years and who were of healthy status. Ineligibility criteria were a history of previous head injury, a neurological or cardiovascular disease, or a physical limitation that interfered with the testing protocol (fatigue, illness, and dizziness). Withdrawal criteria included the participant not being able to completely participate in the test or an unwilling to participate, or taking a medication or agent that affected the nervous system.

Experimental paradigm

The QEEGs of Thai professional female soccer players were recorded 3 times: 2 weeks before the competition, 1 week before the competition, and 1 week after the competition. Always the EEG was collected, athletes maintained course practices from the SAT staff coach, and sleep control (good and enough). During the competition, their performances were observed and scored based on feedback from the staff coach. The average performance scores (APS) during the competition were analyzed and accompanied the results of the QEEG to classify the brain central fatigue and brain patterns.

Before initiating the experiment, the subjects were familiarized with QEEG measurements by viewing a demonstration and receiving an explanation of the instruments, tasks and procedures. Then, the researcher prepared the subjects for QEEG measurements, and the QEEGs of the Thai professional female soccer players were recorded. The QEEG measurement procedures began with the subjects seated in a chair in a relaxed position, and then the QEEGs were recorded for 5 minutes. During the QEEG measurements, the subjects were instructed to keep their eyes opened.

Data acquisition

EEGs were recorded from 19 channels including Fp_1, F_3, C_3, P_3, O_1, F_7, T_3, T_5, F_z, Fp_2, F_4, C_4, P_4, O_2, F_8, T_4, T_6, C_z, and P_z according to the standardization of the international 10:20 system. An electrode cap (19 electrodes) was placed on the participant's skull. All leads were referenced to electronically linked earlobes (reference: A1 – the right ear and ground: A2 – the left ear). A Brain Master Discovery 24E system was used in this study to record EEG signals at a sampling rate of 256 Hz/24 bit data and a bandwidth of 0.43-80 Hz. The EEG electrode impedances were below 5 kΩ.

Data analyses and statistics

The recorded QEEG data were analyzed by using the Z-scored FFT method. The results of brain connectivity were represented in terms of coherence. The objective of using brain connectivity is to gather knowledge of the neuroscience variables base on computation, methodology, and experiments. It is of special interest to understand the tripartite relationship among anatomical connectivity, brain dynamics and cognitive function. For this study, the calculated coherence results were displayed as brain connectivity. Coherence analysis is an approach used to measure the similarity of frequencies between two different channels regardless of amplitude and phase (Collura 2008). Where Xf and Yf represent the Fourier magnitude of the two channels and measure the similarity of the shapes of the two signals' FFT spectra, regardless of phase and independent of their absolute or relative magnitudes.

$$\text{Coherence} = \left(\frac{(\sum |X_f||Y_f|)^2}{\sum |X_f|^2 \sum |Y_f|^2}\right) \quad (1)$$

A mathematical Gaussian curve, or "bell shaped" curve, was applied to estimate probabilities by using the auto- and cross-spectrum of the EEGs. This was defined as the Z-scored FFT method (Thatcher et al., 2004-2007). This method could identify the brain regions that were de-regulated and that deviated from the expected values. The recorded EEGs were described in terms of the selected frequency band, and the standard deviation and mean of the normative database were calculated (Collura et al., 2010) and (Thatcher, 1998).

$$Z_{\text{FFT}} = \frac{X_i - \bar{X}}{SD_x} \quad (2)$$

where X_i is the recorded EEG of the selected frequency band, SD_x is the standard deviation of the normative database, and $\bar{X}$ is the mean of the normative database. In addition, Z-scored FFT information was analyzed via brain connectivity. This method included 64 pairs of channels as follows: Fp_1-F_3, Fp_1-C_3, Fp_1-P_3, Fp_1-O_1, Fp_1-F_7, Fp_1-T_3, Fp_1-T_5, F_3-C_3, F_3-P_3, F_3-O_1, F_3-F_7, F_3-T_3, F_3-T_5, C_3-P_3, C_3-O_1, C_3-F_7, C_3-T_3, C_3-T_5, P_3-O_1, P_3-F_7, P_3-T_3, P_3-T_5, O_1-F_7, O_1-T_3, O_1-T_5, F_7-T_3, F_7-T_5, T_3-T_5, Fp_2-F_4, Fp_2-C_4, Fp_2-P_4, Fp_2-O_2, Fp_2-F_8, Fp_2-T_4, Fp_2-T_6, F_4-C_4, F_4-P_4, F_4-O_2, F_4-F_8, F_4-T_4, F_4-T_6, C_4-P_4, C_4-O_2, C_4-F_8, C_4-T_4, C_4-T_6, P_4-O_2, P_4-F_8, P_4-T_4, P_4-T_6, O_2-F_8, O_2-T_4, O_2-T_6, F_8-T_4, F_8-T_6, T_4-T_6, Fp_1-Fp_2, C_3-C_4, O_1-O_2, T_3-T_4, F_3-F_4, P_3-P_4, F_7-F_8, and T_5-T_6. The QEEG value was calculated by equation (1).

$$X = \frac{1}{N}\left(\sum_{i=1}^{N} Z_i\right) \quad (3)$$

where X is the QEEG value of brain connectivity (coherence), Z_i is one pair of QEEG channels, and N is the numbers of channels pair. The objective of this study was to study brain central fatigue by comparing brain connectivity (coherence) in the delta frequency band. Thus, the participants were classified into two groups (key players, n=13 and substitute players, n=16). The average values of brain connectivity for all subjects were calculated at every point on the brain. Therefore, the average value of brain connectivity (coherence) in the delta frequency band was used to compare each condition (2 weeks before the competition and 1 week before the competition and after the competition) between the groups. Additionally, the different values between one week before and after the competition were compared between groups by an independent paired-sample t test to confirm that brain central fatigue occurred in key players of the team.

Pre-processing

The QEEG data that contained no artifacts were selected for analysis using NeuroGuide software. The reliability percentages of the data were assessed using the split half and test retest methods, for which the values should be greater than 90%.

RESULTS

The objective of this study was to compare the brain activity between key and substitute players of the Thai professional female soccer team. Therefore, the results were reported as brain central fatigue after the competition compared between groups. The effects of brain central fatigue were clearly observed in brain connectivity (coherence) in the delta frequency band (0.1-3 Hz). The brain central fatigue revealed lower interactions (represented by blue lines) for comparison among brain positions, as shown in Figure 1 (after competition condition). Additionally, the brain connectivity (coherence) of athletes was compared before and after the competition. The brain commonly returns to a normal state after the competition. This phenomenon was observed in the substitute players. Contrastingly, key players (on the ground players) exhibited the brain central fatigue phenomenon, and the results are shown in Figure 1.

S_n is the subject number (i.e., 1, 2, 3,…, 13). The blue lines indicate lower coherence than the normative database, red lines indicate higher coherence than normative database, and no line at all indicates that the coherence was equivalent with the normative database. APS is the average performance score given by the staff coach. The numeral is the QEEG value calculated from X in (3).

There was an outstanding result from the key player (S_{12}). The results showed lower interactions of brain connectivity after the competition compared with her normal state (2 weeks before competition). In addition, S_{12} produced an excellent performance in the competition, finishing with 2 goals, and all the staff coaches gave her full scores. Therefore, the lower interaction of brain connectivity in the delta frequency band of this player (S_{12}) may represent brain central fatigue. On the other hand, this is the brain connectivity (coherence) pattern that corresponded to the peak performance of the athlete in the last competition (see the

QEEG value of S_{12} in Figure 1). Figure 2 shows the brain connectivity patterns of substitute players of the Thai professional female soccer team. These players demonstrated a different pattern of brain connectivity (coherence) than that elicited from the key players. Most of the substitute players did not exhibit the brain central fatigue phenomenon after the competition.

S_n is the subject number (i.e., 1, 2, 3,…, 16). The blue lines indicate lower coherence than the normative database, the red lines indicate higher coherence than the normative database, and no line at all indicates that the coherence was equivalent with the normative database. APS is the average performance score given by the staff coach. The numeral is the QEEG value calculated from X in (3).

Moreover, Figure 3 reveals the QEEG value (coherence) of key players at being three times. The key player (S_{12}) result shows the difference in QEEG values from 2 weeks before the competition and 1 week after the competition, at which time athletes normally return to a normal state (2 weeks before the competition). This result indicates that athletes experience a brain central fatigue effect. Conversely, the QEEG values (coherence) of substitute players did not indicate a brain central fatigue effect, as shown in Figure 4. These athletes have

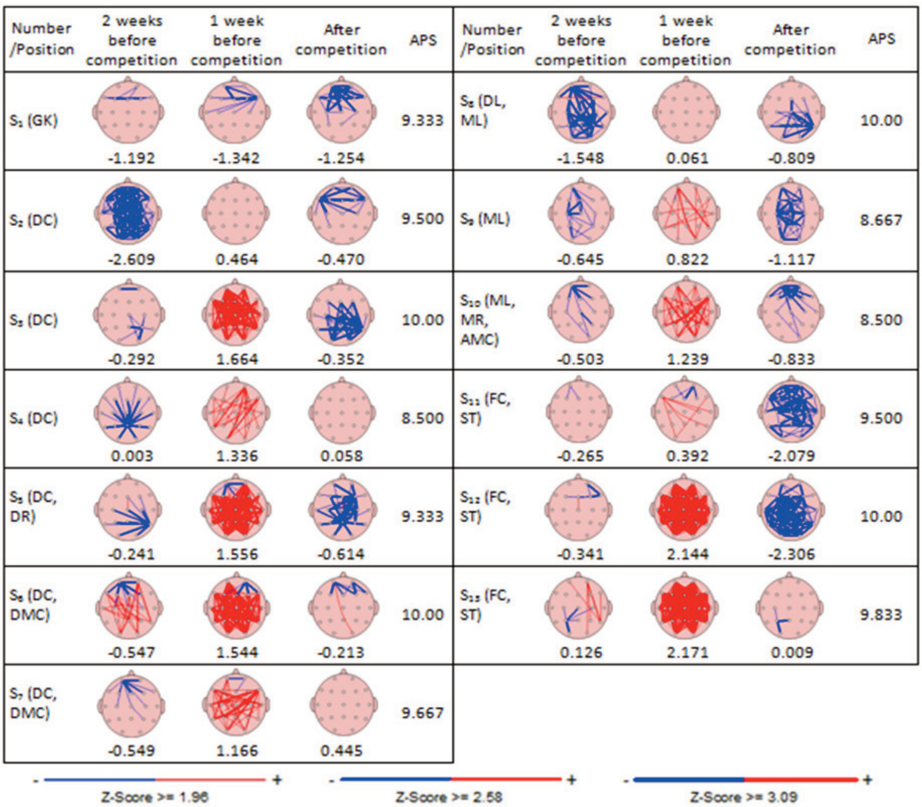

Figure 1. Results of Z-scored FFT for delta-band brain connectivity (coherence) of key players (on ground players) of the Thai professional female soccer team

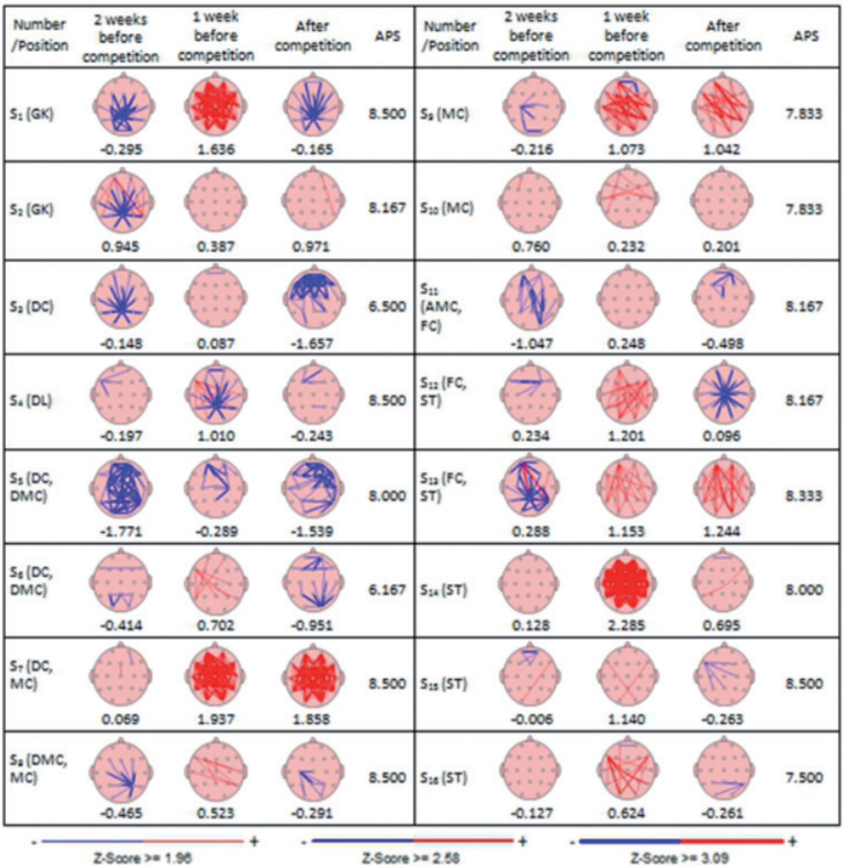

Figure 2. Results of Z-scored FFT for delta-band brain connectivity (coherence) of substitute players of the Thai professional female soccer team

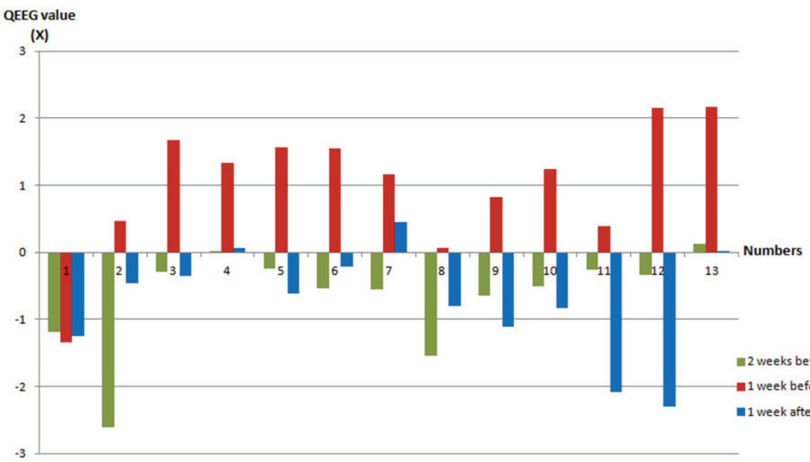

Figure 3. Results of QEEG values for delta-band brain connectivity (coherence) of the key players in the first, second and the third recording

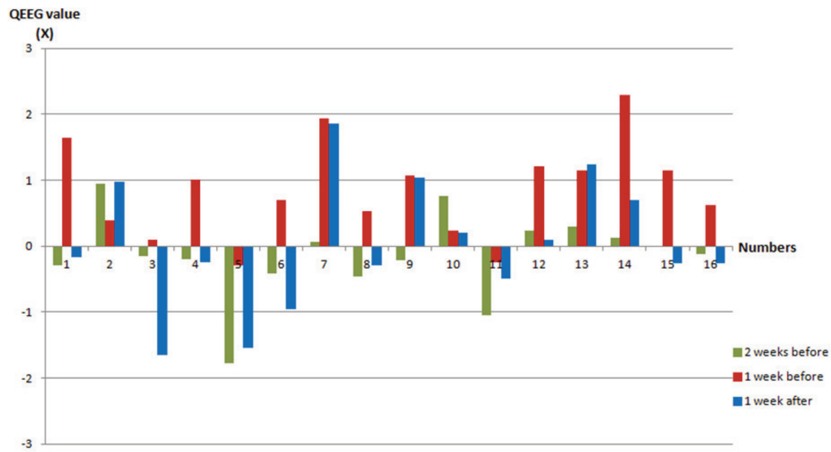

Figure 4. Results of QEEG values for delta-band brain connectivity (coherence) of the substitute players in the first, second and the third recording

Table 1. Comparison of QEEG values of key (on the ground) and substitute players of the Thai professional female soccer team

Research condition	Brain connectivity (delta frequency band)	Key players group N=13 MEAN	Substitute players group N=16 MEAN	p-value (2-tailed)
Eyes open	After competition	-.73380	.01490	.035*
	Difference between pre-match 2 and after match	1.8882	.94130	.003*
	Average performance score	9.4487	7.9479	.000*

* significant at $p<0.05$

almost equal QEEG values at 2 weeks before the competition and 1 week after the competition.

The statistical analysis of the differences was conducted by independent paired-sample t tests, as shown in Table 1. After the competition, the brain connectivity (coherence) between the key and substitute players was significantly different (p=.035). Moreover, there was the significantly different result of brain connectivity (coherence; delta frequency band) between a week before the competition and post-match (p=.003). Thus, after the competition, key players presented brain central fatigue and their brain connectivity (coherence) patterns were different. Moreover, the average performance scores between key and substitute players were significantly different (p<.000), which was correlated with different brain activity patterns.

DISCUSSION

The main finding of this study was that brain central fatigue occurs after competition. The brain connectivity was studied in terms of coherence analysis of the delta frequency band, which represents brain central fatigue. The blue lines in the brain topographic maps represent decreased interactions in the brain, which could indicate brain central fatigue. Thus, the interaction intensity of anatomical links between units within the nervous system could result in perception. Therefore, a lower interaction of brain connectivity could indicate deceased perceptive ability, such as delayed decision-making processing, slow responses to acute situation, and inadequate information-management to induce sensation. Practically, the occurrence of this phenomenon could be used for predicting athletes' performances, which might decline during the competition. Furthermore, the comparison of brain connectivity between key and substitute players corresponded and supported this phenomenon (p=.035 and p=.003). The results were significantly different, which demonstrated that the key players experienced brain central fatigue and this showed as their performance decreased. However, the average performance score of the key players was significantly higher than that of the substitute players. This refers to the different brain patterns among key and substitute players. Therefore, athletes who have a brain connectivity pattern similar to player S_{12} (as shown in Figure 1) may have shown their peak performance during the last competition.

Physical changes could affect the brain activities represented in brain waves. When hypoglycemia occurs, slow waves are increased in the brain (Tallroth et al. 1990). Overnight fasting also results in similar brain activities including decreased absolute delta power and increased theta and alpha powers (Hoffman and Polich 1998). Knyazev (2007 and 2012) proposed the delta oscillations concept, which is the integration and synchronization of cerebral functions. These are processes reflected in brain activity that maintain homeostasis and motivation. Moreover, interactions between the neurotransmitter system and brain waves have been studied in terms of the P300 paradigm. It was reported that excitation of dopamine neurons can induce P300 generation. For brain stimulation, it has been proposed that rewarded termination (dopaminergic) is more intimately linked to arousal than the onset stimulation, which relies on the association of reinforcement processes (Panksepp 1998). Dopamine is a neurotransmitter that is involved in psychological and physiological factors. It regulates motivation, arousal, muscular coordination, and endurance performance. Intense exercise could decrease dopamine levels, which results in decreased motivation. Therefore, these factors lead athletes to perform more poorly (Bailey et al. 1993). Several previous studies have demonstrated the correlation of mental fatigue and brain waves as delta and theta oscillations. They found increasing brain waves when mental fatigue occurred (Kiroy et al. 1996, Lal and Craig 2002, Lal and Craig 2005, Makeig and Jung 1996, and Yamamoto and Matsuoka 1990). Electroencephalography (EEG) coherence is widely used as a quantitative measure of signal synchronization. Coherence is recorded from a pair of electrodes as a function of frequency (Halliday et al. 1995). The resulting explanations of the EEG spectral coherence could be presented as an index of functional coupling (Gerloff et al. 1998, Thatcher et al. 1986), mutual information exchange (Rappelsberger and Petsche 1988), functional co-ordination (Gevins et al. 1998), or integrity of cortical neural pathways (Locatelli et al. 1998). The study by Babiloni et al. (2011) hypothesized that the putting performance of expert golfers was related with alpha rhythms including their amplitudes and functional coupling (EEG coherence). This assumption was based on the principle of neural activities. When two cortical areas produce coordinated activities, linear interrelatedness and high spectral coherence recorded from EEG rhythms over cortical areas were found. According to this assumption, the increased EEG spectral coherence is associated with perception, cognition, and motor processing (Sauseng et al. 2005, Babiloni et al. 2006, Vecchio et al. 2007, and Vecchio et al. 2010).

However, the results of this study could represent an alternative way to accurately assess players. The unstable performance of an elite female soccer player might be due to other factors such as the recovery period from neuromuscular fatigue and biochemical changes (Andersson et al. 2007). Due to unstable technical and physical performances between the first and second halves of official soccer matches, the results from the present study could indicate an advantage. For competitive sports with prolonged duration, it is useful to classify soccer players who have the most relevant technical and specific skills. This approach would be an effective tool for player selection and could lead to more successful matches (Rampinini et al. 2009). Additionally, these results also support EEG neurofeedback as a potential diagnostic tool for use as a treatment protocol for chronic fatigue syndrome (CFS) symptoms (James and Folen 2010; Pachalska et al. 2017) and to create the possibility of peak performances (Graczyk et al. 2014).

CONCLUSION

This study evaluated brain connectivity in the delta frequency bands to elucidate the effect of competition on brain activity and sport performance. The present study found QEEG coherence in the players who exhibited brain central fatigue. The brain connectivity (coherence) could identify the brain central fatigue based on the magnitude of the connectivity. When the connectivity was lower than the normal condition (no line or red lines changed to blue line), this was interpreted as the occurrence of brain central fatigue. This result indicates that the players had low sensitivity and low affective perceptual responses to acute bouts of competitions. Therefore, brain connectivity (coherence) could be used to predict an athlete's brain central fatigue after competitions. The results from this study could be used to provide information to staff coaches to select the best performing players and could be an alternative way to accurately assess players and benefit the competitive sports community.

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