Quantitative EEG evaluation for performance level analysis of professional female soccer players

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Abstract Quantitative electroencephalography (QEEG) was used to investigate the brain activity of Thai professional female soccer team players who exhibit high performance. The QEEGs of 29 players were recorded three times: twice before a competition (once a week) and a week after a competition. The results of the brain topographic map (absolute power) in the alpha frequency band and the brain connectivity (coherence) in the delta frequency bands represented their anxiety and decision-making levels, respectively. These phenomena occurred in the brain activities of the athletes, which could be used to predict their performances during the competition. Moreover, the value of the correlation coefficient between the brain activity ranking and average performance score revealed a moderate to good relationship ($r_s = .586$, $p = .001$). These results support the association between brain activity and performance level during competition.

Keywords Quantitative electroencephalogram (QEEG) · Brain topographic map (Absolute Power) · Brain connectivity (Coherence) · Anxiety · Decision-making · Peak performance · Alpha frequency band · Delta frequency band

Introduction

For decades, understanding the skill acquisition process has been a key challenge in sports. One of the most valuable goals of athletes is achieving their peak performance

during a competition. There are three ways in which peak performance is used cognitively, subjectively, and physiologically (Cashmore 2008). There are several methods to used evaluate the performance of athletes, and studying the electrical brain activity using electroencephalography (EEG) is one approach (Thompson et al. 2008). In a study of golf putting, it was found that the EEG spectral power depended on skill level, which demonstrated a difference in the frontal theta frequency and the parietal alpha-2 frequency power values. There were also cortical activity differences in terms of EEG that, could distinguish between novices and experts in golf putting skill (Baumeister et al. 2008). Additionally, studies of the brains of athletes, including elite fencing and elite karate athletes demonstrated that the neural efficiency in athletes could be characterized by reduced cortical activity during hand movements (Percio et al. 2008) and upright standing (Percio et al. 2009) and could be used to distinguish athletes from non-athletes.

In 1999, Hardy explained the cusp catastrophe model of anxiety and performance (Hardy 1999). On the day of competitions, anxiety is a key factor that affects the physiological status and performance of athletes. For the competitive situations, especially sports competitions, anxiety is common. The effects of anxiety are highly debilitating to athletes' performances (Martens et al. 1990). Anxiety is presented in various forms and is associated with human emotional and cognitive reactions in response to a stimulus, presenting apprehension and trepidation. Generally, anxiety corresponds to the perception of threat, assuming that the persons are aroused and reflects their physiology response to the stimulus (Cashmore 2008). The Individual Zones of Optimal Functioning (IZOF) model has also been applied to regulate anxiety the pre-competitions. Moreover, this model acts as a framework to handle

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performance-related emotions in order to examine the relationships among anxiety and emotion-focused and action-focused coping (Nicholls 2010).

In addition, psychophysiological metrics (i.e., EEG alpha and gamma frequencies) are associated with a range of cognitive processes including emotional processing, focused attention, memory encoding and retrieval, etc. These factors mainly affect deadly force judgment and decision making (DFJDM). These metrics could be developed to distinguish experts from novices by evaluating the outcome and processes of brain activity, such as changes from rest alpha combined with workload (Johnson et al. 2014). A previous study of correlation between neuronal activity and decision-making primarily relied on analysis of the firing rate patterns of neurons. Monkey behaviors were evaluated, and the cortical circuits were recorded for successive tasks that were performed one-by-one. The experimental monkeys were trained to perform sensory, motor, and cognitive tasks (Gold and Shadlen 2007). Nacher et al. (2013) stated that the coherent delta-band oscillations reflect the linkage between the parietal and frontal cortical circuits during decision-making. Moreover, the functional delta oscillations present synchronization of brain activity and autonomic functions. These are associated with motivational processes related to reward and atavistic defensive mechanisms. Thus, during the cognitive process, functional delta oscillations are primarily related to attention and the detection of motivational stimuli from the environment (Knyazev 2012). Therefore, QEEG features, including the theta/beta and the theta/SMR ratio, may represent important sources of information that can be used for detecting sporting achievements after basketball practice (Zaranska et al. 2013). The study of Bailey et al. (2008) evaluated brain activity in subjects while performing a graded exercise test. The results of the investigation demonstrated that there was an association between brain activity and exercise intensity. Furthermore, the results of biofeedback intervention in the study by (Dziembowska et al. 2016) presented changes in the power spectra of both theta and alpha brain waves and asymmetry of alpha waves in male athletes. These changes could suggest that there is superior self-control in the central nervous system and better flexibility of the autonomic nervous system among experts compared to novices.

The purpose of this study was to investigate the brain activity in Thai professional female soccer team players who exhibit high sport performance and skill. Here, we hypothesized that the brain phenomena will occur on the athlete's brains before the competition, and the brain activity was able to predict the athlete's performance during the competitions. Firstly, the results of the brain topographic map (absolute power) showed that the quantity of the alpha frequency band in the posterior head region

was lower than the normal condition. This represents the cognitive anxiety response. Secondly, the brain connectivity (coherence) revealed higher connectivity of the delta frequency band in all positions of the brain, which refers to good decision-making. These two phenomena could indicate the athlete's performance during the competition.

Materials and methods

This study was designed to examine the brain activity of athletes, which could shed light on their performance during competition as shown in Fig. 1.

Participants

The volunteers participated in the 2014 AFC Women's Asian Cup. Twenty-nine athletes in Thai professional female soccer team took part in this study, which consisted of three goalkeepers (GK), eight center defenders (DC) and a full back (DL/DR), eleven defensive center midfielders (DMC) and center midfielders (MC), and seven forwards (FC) and strikers (ST). The statistics of twenty-nine participants can be described as follows: the mean age $\pm$ SD was 24.17 ± 2.633 years with an age range of 19–29 years, the mean height $\pm$ SD was 162.0 ± 5.552 cm with a height range between 153.0–173.0 cm and the mean weight $\pm$ SD was 55.10 ± 5.853 kg with a weight range of 44–69 kg. Twenty-six participants were right leg and arm dominant,

Fig. 1 Summary of the study

and three participants were left leg and arm dominant. All participants met the inclusion criteria of this study, as follows: they were professional female soccer players aged between 19 and 29 years, being involved in playing soccer for at least 3 years and were of healthy status. They had normal vision for the duration of the experiment. In addition, 24 h before testing, the participants were not allowed to attend any intensive training sessions or examinations. Fail to follow this condition, the subjects will be excluded. The volunteers who had a history of previous head injuries, neurological diseases, cardiovascular conditions, or use of medications or drugs were excluded. All of experimental procedures were performed under the rules and regulations of the Center of Ethical Reinforcement for Human Research, Mahidol University (COA No. MU-CIRB 2015/143.2411). All participants signed an informed consent after the study was explained to them by the researcher. The collected data were treated confidentially.

Materials

The instrumentation used in this study was a Brain Master Discovery 24E, which consisted of 19 channels at the recording the positions Fp₁, F₃, C₃, P₃, O₁, F₇, T₃, T₅, F_z, Fp₂, F₄, C₄, P₄, O₂, F₈, T₄, T₆, C_z, and P_z. The collected data were analyzed using NeuroGuide software, and SPSS (version 19) was used for the statistical analysis. All results are presented as the mean and standard deviation. The normal distribution of all of the results was verified using the Kolmogorov–Smirnov (K–S) test. The association among the variation values of the brain topographic map (absolute power), brain connectivity (coherence) and the average performance score were explored using the Spearman rank correlation coefficient. For predicting of athletes' performances, the correlation between the brain activity ranking and the average performance score were analyzed using the Spearman rank correlation coefficient.

Procedure

Before an examination trial, the participants were familiarized with QEEG measurements by allowing them to observe a demonstration and explaining the instrument, the tasks and the procedures. Next, the researcher prepared the participants for QEEG measurements. Then, the QEEGs of the Thai professional female soccer team players were recorded. The recordings were conducted twice in 2 weeks (once a week) before the competition. For the QEEGs measurements, the participants were asked to sit on a chair in a relaxed position, and the QEEG was recorded for 5 min. The performance scores of Thai professional female soccer team players during the competitions were rated and feedback was given by their coaches. In addition, the overall performance level was also

classified by the average of their performance scores, and the results of the brain recordings, including brain topographic map (absolute power) and, brain connectivity (coherence). One week after the competition, the QEEGs were evaluated to verify the differences that occurred in the brain recordings prior to and after the competitions.

EEG recording

According to the standardization of the international 10:20 system, the 19 electrodes were placed on the surface of the participant's scalp. All leads were referenced to linked earlobes (reference: A1—the right ear and ground: A2—the left ear). For the EEG signals, a sampling rate of 256 Hz/24 bit data and an EEG channel bandwidth of .43–80 Hz were used. The EEG impedances were below 5 kΩ. During the QEEG measurements, the participants were instructed to keep their eyes open.

Data analysis

The data were analyzed using the Z-scored FFT method. The results were represented as the absolute power and coherence. The application of the mathematical Gaussian curve, i.e., “bell curve”, via the estimation of probabilities using the auto- and cross-spectrum of the EEGs is defined as Z-scored FFT method (Thatcher et al. 2004–2007). This method was used to identify the brain regions that were de-regulated and departed from the expected values, as described by Eq. (1).

$$Z_{\text{FFT}} = \frac{X_i - \bar{X}}{SD_x} \quad (1)$$

where X_i is the recorded EEG of the selected frequency band, and SD_x is the standard deviation of the normative database (Collura et al. 2010), (Thatcher 1998), $\bar{X}$ = mean of normative database (Collura et al. 2010), (Thatcher 1998). This Z-scored FFT information was further analyzed via brain topographic maps and brain connectivity, as follows.

1. Brain topographic map: Topographic EEGs present a spatial representation of raw EEG data, such as voltage amplitude, a derived parameter such as power for a given frequency band, or peak latency. (Yasser 2010). In this paper, the results are displayed as topographic maps by calculating the absolute power. The absolute power represents activation of the brain corresponding to the amount of a specified frequency within the EEG (Malik et al. 2012).
2. Brain connectivity: The objective of brain connectivity is to aggregate the knowledge of computational neuroscience, neuroscience methodology and experimental neuroscience with a special interest in understanding the tripartite relationship between anatomical

connectivity, brain dynamics and cognitive function. In this paper, the brain connectivity was calculated based on coherence. Coherence analyses measure the similarity of frequency between two channels regardless of amplitude and phase (Collura 2008). This can be described by Eq. (2) as a spectral morphology comparison, as follows.

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

where X_f and Y_f represent the Fourier magnitude of the two channels and measures the similarity of the shapes of the two signals' FFT spectra, regardless of phase and independent of their absolute or relative magnitudes.

The Spearman rank correlation coefficient is a non-parametric analog of the Pearson correlation. The given symbol of the Spearman rank correlation is r_s (sometimes called Spearman's rho) and is used for ordinal data analyses. The Spearman rank correlation examines the disparity between the two sets of rankings by looking at the difference between the ranks of x and y assigned to each subject, given the value d . The value of r_s is determined by the computational formula:

$$r_s = 1 - \frac{6 \sum d^2}{n(n^2 - 1)} \quad (3)$$

where $\sum d^2$ is the sum of the squared rank difference, and n is the number of pairs (Portney and Watkins 2009).

Pre-processing

The data were analyzed using NeuroGuide software by selecting only the part of the QEEG data that contained no artifacts (red highlighting or red circles indicate the QEEG data that contained no artifacts and black highlighting or black circles indicate the QEEG data that contained artifacts). The reliability percentages of the data were performed using the split half and test retest methods, which should correspond to values greater than 90%.

Results

The obtained data, including the brain topographic map (absolute power), the brain connectivity (coherence) and the average performance score were normally distributed. Table 1 shows the results of the normal distribution test of the brain topographic map (BT), the brain connectivity (BC), and the average performance score (APS). The BT

was defined as the mean absolute power in the alpha frequency band (8–12 Hz), and the position was the posterior head region (P_3 , O_1 , P_4 , O_2 and P_z). The BT revealed variation values between the 2 weeks before the competition (1st recording) and 1 week before the competition (2nd recording), which referred to the cognitive anxiety response. The BC was defined as the mean coherence in the delta frequency band (.1–3 Hz), and the location represented all of the positions on the brain. The BC represented the affective and perceptual responses to acute bouts or decision-making responses. The BC indicated the variation value of the brain connectivity between 2 weeks before competition (1st recording) and 1 week before the competition (2nd recording). The APS revealed the average performance scores that were acquired from three staff coaches, who rated the athletes' performances during the competition, as shown in Table 2. The Z Kolmogorov–Smirnov tests were used to analyze the normality of the distributions of the BT, BC, and APS results. The results were not statistically significant, as shown in Table 1.

Brain topographic map for anxiety

The experimental results are represented in the form of topographic maps (absolute power), as shown in Table 3. The data were recorded from Thai national female soccer team players and indicate that the players have anxiety before competing in a match. The anxiety levels increased for recording made closer to the time of competition. The result of the anxiety level showed that the quantity of the alpha frequency band in posterior head region was less than that in the normal condition (displayed in blue color for the demonstration of this area), indicating the cognitive anxiety response. This investigation focused on the EEGs recorded from 5 sites (P_3 , O_1 , P_4 , O_2 and P_z). The anxiety phenomenon was reflected by a low quantity of the alpha frequency band in the posterior head region and returned to the normal state after the competition, as shown in Table 3. In this result, Table 3 illustrates the anxiety phenomenon in terms of the brain topographic maps (absolute power) of only the key players (on ground players) of the team.

The present study considered the variation in values of brain topographic map (absolute power) and average performance scores. The variation value of the brain topographic maps (BT) is the variation in the brain topographic maps between the first recording before the competition (2 weeks before the competition) and second recording before the competition (1 week before the competition) recorded at the posterior head region (P_3 , O_1 , P_4 , O_2 and P_z). This method was used because individual brain topographic maps in the normal condition are not equivalent. Individual normal EEGs reflect human behaviors and mental functions, etc. The average performance scores

Table 1 Result of normality of the distributions of the brain topographic map (BT), brain connectivity (BC), and average performance score (APS) (n = 29)

Research condition	QEEG values	Mean	SD	Test K–S	P value (2-tailed)
Eyes open	BT	.0510	.42707	1.222	.101
	BC	1.4004	.67087	.326	1.000
	APS	8.6207	.98792	.912	.377

Table 2 The average performance scores (APS) for three staff coaches (n = 29)

N	Average point	N	Average point	N	Average point	N	Average point
S ₁	9.333	S ₉	10.00	S ₁₆	6.167	S ₂₃	8.000
S ₂	8.500	S ₁₀	8.667	S ₁₇	8.500	S ₂₄	8.167
S ₃	9.333	S ₁₁	9.500	S ₁₈	7.500	S ₂₅	8.000
S ₄	8.500	S ₁₂	8.500	S ₁₉	8.500	S ₂₆	8.167
S ₅	8.500	S ₁₃	10.00	S ₂₀	6.500	S ₂₇	7.833
S ₆	10.00	S ₁₄	9.833	S ₂₁	8.500	S ₂₈	7.833
S ₇	10.00	S ₁₅	9.500	S ₂₂	8.333	S ₂₉	8.167
S ₈	9.667						

assigned by three staff coaches were used as an estimate of the performance of the players during the competition. However, the results of the correlation analysis between the brain topographic maps and average performance scores demonstrated little to no relationship and was not significant ($r_s = .081$, $p = .677$). Therefore, the anxiety condition exhibited in the brain topographic maps could not predict the athlete's performance during the competition.

Brain connectivity for decision-making

The QEEG recordings of the Thai professional female soccer team players revealed specific patterns that clearly showed good decision-making. The results were demonstrated in the form of brain connectivity (coherence), as shown in Table 4. The good decision-making level was indicated by the connectivity of the delta frequency band across all positions of the brain. The brain connectivity analysis revealed higher connectivity compared to the normal condition (no line, or a blue line changed to a red line), indicating that there were more affective and perceptual responses to acute bouts during the competition. This phenomenon increased when the time until the competition decreased, and it returned to the normal state when the competition finished. For these results, Table 4 illustrates the good decision-making phenomenon exhibited by the key players (on ground players) on the team. These results correspond to the brain connectivity (coherence). This investigation considered EEGs that were from all positions of the brain (Fp₁, F₃, C₃, P₃, O₁, F₇, T₃, T₅, F_z, Fp₂, F₄, C₄, P₄, O₂, F₈, T₄, T₆, C_z, and P_z).

The value of the correlation coefficient between the variation value of brain connectivity (coherence) and the average performance score presented a moderate to good relationship and was significant (Portney and Watkins 2009) ($r_s = .538$, $p = .003$). The brain connectivity (BC) value at 1 week before the competition (2nd recording) had a higher connectivity than the normal condition (2 weeks before the competition or the 1st recording) for the delta frequency band. This revealed the good decision-making level, and may reflect a peak performance level. In addition, Table 4 shows the higher connectivity of the delta frequency band of the key players (on ground players) who have the better physical ability, and these players exhibited higher connectivity than the other players (substitutions) of the team. There was an outstanding result recorded for the key player (S₁₃). All of the staff coaches gave her full scores, and the result of the brain connectivity variation value was much higher than the other players. This result may indicate that that higher brain connectivity of the delta frequency band represents increased athletic performance. In the 2014 AFC Women's Asian Cup, player (S₁₃) also had an excellent performance, finishing with 2 goals, which gave the Thai professional female soccer team the opportunity to qualify for the 2015 FIFA Women's World Cup.

Peak performances of the athletes in brain activity ranking

The present study is the first investigation of peak performance related EEG activity, which investigated the Thai professional female soccer team before and after a

Table 3 Result of the Z-scored FFT for the alpha-band brain topographic map (absolute power) of the key players of the Thai professional female soccer team

S_n represents the subject. Blue colormap indicates amplitudes lower than the normative database, green colormap indicates the normal condition, and red colormap indicates amplitudes higher than the normative database. (Color table online)

Table 4 Results of the Z-scored FFT for delta-band brain connectivity (coherence) of the key players of the Thai professional female soccer team

S_n represents the subject. Blue lines indicate lower coherence than the normative database, Red lines indicate higher coherence than the normative database, and no line indicates that the coherence was not significantly different from the normative data. (Color table online)

Table 5 Result of Z-scored FFT for the brain activity ranking of the peak performance of Thai professional female soccer team players

BT is the brain topographic map (absolute power), BC is the brain connectivity (coherence), and S_n represents the subject. (Color table online)

competition. First, the anxiety revealed in the brain topographic maps (absolute power) was unable to predict peak performance. Second, high connectivity (coherence) was observed, which was related to good decision-making. Good decision-making was interpreted as affective and perceptual responses to acute bouts during the competition. The associations between the variation values of brain connectivity and the average performance scores were analyzed according to Spearman rank correlation coefficients ($r_s = .538, p = .003$), which indicated that the good decision-making level could predict the athlete's performance during the competition. In addition, the Spearman rank correlation coefficient was used to evaluate the association between brain activity ranking and the average performance score. The result revealed a moderate to good

relationship ($r_s = .586, p = .001$), which was derived from the brain activity ranking and the average performance score. The brain activity ranking was calculated from the summation of the brain topographic map (absolute power) ratings and the brain connectivity (coherence) ratings. The rating of the brain topographic map and the brain connectivity were classified on a scale of ten according to the average performance score. The ten rating scale of the brain topographic map comprised very low anxiety conditions, moderate anxiety conditions, and very high anxiety conditions. The ten rating scale of the brain connectivity comprised very good decision-making, moderate decision-making, and very poor decision-making. Therefore, the brain activity ranking scales could predict athletes' performances during the competition. Therefore, this method

can be used as an alternative way for staff coaches to select the players who may have higher performances during an upcoming the competition.

Table 5 shows examples of the brain activity ranking scales of the players who exhibited high performance levels during the competition. For the Thai professional female soccer team players, four players showed higher performance levels compare to the others players. All of the staff coaches recommended this result. The brain topographic maps (BT) and the brain connectivity (BC) of the four players who had higher performance levels during the competition are illustrated in Table 5. The brain activity in terms of BTs recorded from the four players changed from low intensity to normal intensity (blue to green color) before the competition, indicating that the four players could reduce their anxiety and increase their self-confidence prior to the competition. The BC of the four players changed from low connectivity to high connectivity (no line or a blue line changed to a red line) before the competition indicating that the four players could increase their affective and perceptual responses to acute bouts, which refers to good decision-making. Therefore, the brain activity ranking scales can be used to evaluate the athletes before a competition to indicate the players who are likely to achieve their peak performance during the game.

Discussion

Latency of the alpha band in brain topographic maps (absolute power)

According to the experimental results, the anxiety level showed that the quantity of the alpha frequency band in the posterior head region was less than the normal condition. Moore (2000) concluded from seven successive studies that, by using their protocol anxiety decreased as the alpha-band increased. Two studies found that when an alpha suppression protocol was used, anxiety decreased. However, the decreased anxiety level was not as great as the alpha increase due to the treatment. The definition of alpha activity was described as a form cortical idling. The amplitude was inversely related to the number of neuronal populations activated during cognitive and motor processes (Niedermeyer and Lopes da Silva 2005). In accordance with the study of Baumeister et al. (2008), they found that the novice golfers exhibited decreased parietal alpha power during putting compared to experts. The novice golfers did not possess the relevant skill for putting, and therefore their parietal regions were activated. This result indicates that the novices must more actively process unfamiliar cues, which requires more neuronal recruitment in the parietal cortex compared to expert golfers. These results were consistent with the study by Gevins et al. (1997) who

identified increased alpha power with fewer cortical resources after cognitive task training.

The purpose of this study was to evaluate the low intensity level of brain processing (blue color) in the alpha frequency band at the posterior head region (P_3 , O_1 , P_4 , O_2 and P_z), which indicates anxiety. The major functions of the parietal lobe consist of spatial awareness and perception (awareness of body). The primary function of the occipital lobe is the processing, integration, and interpretation of visual stimulation. In addition, the secondary function of the occipital lobe is the perception of the bodily movements (Teplan 2002). Therefore, the analysis of the results in this study was based on the brain topographic map (absolute power) in the quantity of alpha frequency band in the posterior region of the head, which was less than the normal condition.

A comparison between the variation value of the brain topographic map (absolute power) and average performance score showed little to no relationship and was not significant ($r_s = .226$, $p = .238$). The variation value of the topographic map indicated an anxiety condition in the athletes, and this value could not predict their performance during the competition. Generally, the athletes who had high anxiety levels had decreased performance during the competition, although some athletes did not exhibit this pattern. This result may indicate that the players of the Thai professional female soccer team have an appropriate anxiety level for the competition corresponding to arousal. In sport psychology, the performance level depends on the level of arousal. Each athlete should obtain his or her optimal arousal, which is related to interpersonal variables as well as to the specific requirements of the sport, termed the Inverted-U theory (Arent and Landers 2003). Therefore, the magnitude of the brain topographic map (absolute power) of the alpha frequency band in the posterior head region was lower compared to normal conditions, which revealed the anxiety condition but could not predict the athletes' performances during the competition.

Latency of the delta band in brain connectivity (Coherence)

The present study used brain connectivity in terms of the coherence analysis of the delta frequency band, which revealed the decision-making of athletes. Nacher et al. (2013) demonstrated that the coherence oscillations of the delta frequency band between parietal and frontal cortices during decision-making were components of a somatosensory discrimination task. In particular, the magnitude of the delta-band coherence could be modulated by the different decision preferences. Generally, delta-band oscillations are associated with slow-wave sleep (SWS; Hobson and Pace-Schott 2002). Knyazev (2012) posed a

key question regarding delta-band oscillations as to whether or not they represent the same underlying mechanism during SWS and waking states. The correlation among delta waves, autonomic processes, and metabolic processes indicates that they may be involved in the integration of brain activity, including homeostatic and motivational processes. This study supports the delta oscillations concept (particularly during sleep), which may participate in the synchronization of cerebral activity with autonomic functions. Moreover, a study by (Fries et al. 2008) found an association of delta-band oscillations among individual cortical areas, including a monkey with high attention and the human in primary motor cortex. It has also been reported that, during concentration, the delta-band oscillations enter into a rhythm of external sensory events (Saleh et al. 2010). This occurrence as a result of the neuronal activities distributed across the parietal and frontal lobe cortices are related to the mechanisms responsible for decision-making (Hoshi and Tanji 2004). The results of this study support the idea that the high connectivity (coherence) of the delta frequency band corresponds to good decision-making. This phenomenon in the present study shows abundant connection among the positions, which extends to all positions of the brain. This result indicates that the brain rapidly detects motivational noticeable stimuli in environment, communications, cognitive processes and responses. Therefore, the athletes who have good decision-making exhibit higher brain connectivity compared to their normal conditions.

The statistical analysis between the variation values of brain connectivity (coherence) and the average performance score showed a moderate to good relationship correlation coefficient ($r_s = .558$, $p = .002$), indicating that athletes who have high connectivity may exhibit their peak performance during the competitions. In sport psychology, the most significant goal in athletes' careers is achieving peak performance, as peak performance cannot be constant and maintained all the times. However, Cashmore (2008) stated that there are three facets to reaching peak performance, which include subjectively, physiologically and cognitively. This study focused on the cognitive domain, which is related to the way humans process, use, and manage information to understand the world. Consequently, the good decision-making detected by brain connectivity could predict the peak performance of athletes during the competition.

Correlation between anxiety condition and decision-making

The anxiety condition is defined as an emotional state that is associated with fear or worry, including a negative aspect of stress. Anxiety can be result of physiology (somatic) and psychological status (cognitive) that affects an

athlete's performance. In term of psychological responses, anxiety symptoms include concentration loss, inability to cope, apprehension feelings, narrowed attention, and fear of failure. These symptoms are related to brain activities (Cashmore 2008). The present study suggests that the anxiety levels revealed by the quantity of the alpha frequency band measured from the posterior head region were less than the normal condition, indicating a cognitive anxiety response. Thus, when the competition is approaching, the athletes required more somatosensory information processing than during normal state. This result is consistent with a report by Wrisberg (2001), who concluded that the novice state can be characterized by stimulus identification that involves the perceptual processes; both the internal and external information of the motor tasks were found to be relevant. Although experts can filter information, they mostly focused on decision and strategy processes. This idea is supported by the results of the brain connectivity (coherence). The athletes exhibited a low alpha frequency band (anxiety condition), and therefore they cannot focus on decision-making, which correspond to negative effects on athletic performance.

The statistical analysis comparing the brain activity ranking scales and the average performance score showed a moderate to good relationship and was significantly ($r_s = .586$, $p = .001$). The correlation value tended to increase and was higher than the analysis of the brain connectivity and the average performance score. Before the competition, athletes' performances could be more accurately predicted using the brain activity ranking (anxiety condition and decision-making).

Clinical applications

Recently, several studies have been reported for reducing anxiety in athletes, including via the use of neurofeedback (Faridnia et al. 2012), the treatment of anxiety disorders (Moradi et al. 2011; Moore 2000), and anxiety management (Bhat 2010). Previous studies have reported that two cases of obsessive compulsive disorder (OCD) were treated via neurofeedback (Hammond 2003). Additionally, Pop-Jordanova and Demerdzieva (2010) presented a case study regarding biofeedback training used in an athlete who was preparing for an Olympic Game competition. This is the first case study in the field that reported preparing an athlete using biofeedback modalities, and the obtained results were very encouraging. Vernon (2005) also found an association between specific cortical patterns and particular levels of performance. It is reasonable to apply neurofeedback as a tool for individual training by re-creating patterns of cortical activity in an attempt to facilitate an athlete's performance. Furthermore, athletes should finish training sessions with relaxation training until the moment of psychosomatic reduction. This suggestion

is useful for sports that involve mental intensity (sports based on speed and stamina, sports games, combat sports). The relaxation technique could be applied during the performance of mentally difficult sports tasks and during relaxation of athletes (Mikicin and Kowalczyk 2015). Furthermore, Division I National Collegiate Athletic Association (NCAA) golfers reported the effect of performance brain training on specific measures of golf skill. It appears that performance brain training may contribute to improving sports measures (Sherlin et al. 2015). Therefore, the brain activity of athletes can be used to indicate their psychological status, which is the primary indicator of physiological performance. Such tools can be used for diagnoses, encouragement, and augmentation of athletes before a competition.

Conclusion

This study proposes a new method of sports performance evaluation based on the brain activity ranking in the alpha and delta frequency bands. The present study found that the players who exhibited peak performance had low anxiety with good decision-making levels, which were evaluated by the QEEG absolute power and coherence. The brain topographic map (absolute power) demonstrated an anxiety condition corresponding to the quantity of the alpha frequency band in the posterior head region. The results showed that there was less alpha frequency compared to the normal condition, referring to the cognitive anxiety response. Regarding brain connectivity (coherence), the players exhibited the good decision-making, which was indicated by higher connectivity compared to normal conditions (no line or a blue line changed to a red line). This result indicated that the players exhibited more sensitive and more affective perceptual responses to acute bouts of the competitions. Therefore, brain activity ranking scales can be used to predict an athlete's performance during competitions. The results from this study can allow staff coaches to choose the highest performance players and will be an alternative method for accurately selecting key players for the competitive sport community.

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