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To cite this article: Dachen Chu, Li-Jung Chen, Ya-Ling Lee, Bao-Lien Hung, Kuei-Ming Chou, Ai-Chi Sun & Shih-Hua Fang (2018) The correlation of brainwaves of Taekwondo athletes with training vis-à-vis competition performance – an explorative study, International Journal of Performance Analysis in Sport, 18:1, 69-77, DOI: [10.1080/24748668.2018.1447205](https://doi.org/10.1080/24748668.2018.1447205)

To link to this article: <https://doi.org/10.1080/24748668.2018.1447205>



Published online: 04 Apr 2018.



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# The correlation of brainwaves of Taekwondo athletes with training vis-à-vis competition performance – an explorative study

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## ABSTRACT

Various studies have reported the correlation between brainwaves electroencephalogram (EEG) and various sports. However, until now, the correlation between EEG signals and the Taekwondo (TKD) have not been reported. The aim of this study is to investigate the correlation of brainwaves of TKD athletes in training experiences and competition performance. The EEG signals were collected from 12 elite male TKD athletes. The  $\beta$ -wave was significantly increased when the heart rate of participant was  $>120 \text{ min}^{-1}$  compared to the resting state. The  $\gamma$ -wave was significantly decreased during foot kicking modalities. In addition, the  $\gamma$ -wave was significantly increased while watching competition films when compared to that in resting state. In the simulation game, before the first and second round, the  $\delta$ -wave of the winner group was significantly higher, whereas the  $\alpha$ - and  $\gamma$ -waves were significantly lower than those of the loser group. While before the third round, the  $\theta$ -wave of the winner group was significantly lower. This study showed that EEG signals were significantly different during the training experiences versus the simulated game of TKD. The results of this study also sheds light on training methods for improving sport performance in future programmes.

## ARTICLE HISTORY

Received 24 October 2017  
Accepted 27 February 2018

## KEYWORDS

Electroencephalogram; open-skill sport; training model; simulated competition

## 1. Introduction

Brainwaves (electroencephalogram, EEG) are divided into five frequencies. Among these, delta ( $\delta$ ) (.5–3.5 Hz) is associated with slow-wave sleep and the restorative properties for the brain and peripheral organs (Benington & Heller, 1995; Rial et al., 2007). Theta ( $\theta$ ) (4–7.5 Hz) and alpha rhythms ( $\alpha$ ) (8–12 Hz) are increased significantly during mindfulness

meditation (Lagopoulos et al., 2009). At the presence of the  $\alpha$  rhythm, one is in the ideal condition to learn new information, perform elaborate tasks, or analyse complex situations (Shaw, 1996). It has been reported that  $\alpha$ -wave has stronger activities in rest state with eyes closed in meditation. A previous study demonstrated that during yoga exercise, the serum cortisol level decreased and  $\alpha$ -wave activation increased (Kamei et al., 2000). The beta ( $\beta$ ) (13–30 Hz) brain rhythm occurs when one is consciously alert, or when one feels agitated, tensed, frightened and when in a state of busyness, anxiety or high concentration. It was reported that during prolonged exercise in the heat, the electrical activity of the prefrontal cortex increased first and showed a progressive decline of the  $\beta$  band until exhaustion (Nielsen, Hyldig, Bidstrup, Gonzalez-Alonso, & Christoffersen, 2001). Gamma ( $\gamma$ ) (31–49.75 Hz) wave is believed to increase many cognitive functions including attention, learning, temporal binding and awareness (Engel & Singer, 2001; Tort, Komorowski, Manns, Kopell, & Eichenbaum, 2009; Womelsdorf, Fries, Mitra, & Desimone, 2006).

Sports science researchers have been interested in the relationship between brainwaves and sports performance. In the normal walking EEG,  $\theta$  and  $\delta$  activities are rare or non-existent. The activated cortex can produce not only  $\gamma$  activity but also  $\beta$ , and sometimes  $\alpha$  activity (Miller, 2007). Most researchers working on brainwaves in the past focused only on closed-skill precision sports and found that the  $\alpha$ -wave in the temporal lobe region is the basis of closed-skill sports (Haufler, Spalding, Santa Maria, & Hatfield, 2000), such as shooting, archery, golf, yoga. Unlike the closed-skill sports that have regular and stable motor execution, open-skill sports are those in which people can barely predict any response to the next movement for each other during the competition, such as Taekwondo (TKD). Therefore, it is more difficult to explore the relationship of brainwave and open-skill sports during training- and competition-related exercises due to the limitation of equipment. A previous study demonstrated that a higher running intensity led to alterations of the level of cortical activity (Mechau, Mucke, Weiss, & Liesen, 1998). In addition, it was also reported that primary motor cortex activity was elevated with incremental exercise intensity during cycling exercise (Brummer, Schneider, Struder, & Askew, 2011). Moreover, there was an increase in  $\alpha 1$  activity immediately after exercise and a decrease in  $\alpha 2$ ,  $\beta 1$  and  $\gamma$  activities 15 min after exercise (Schneider, Askew, Abel, Mierau, & Struder, 2010).

Using wireless Bluetooth transmission EEG, we aimed to measure and compare the brainwaves activity of TKD contestants in different training patterns, before competition and in the rest time between each round of competition.

## 2. Materials and methods

### 2.1 Subjects

Male athletes from the National Taiwan University of Sport TKD team volunteered to participate in this study. The 12 participants who have been rewarded as the top 3 in domestic or international TKD tournaments were included, with those needing to take any medication during this study being excluded. The average age was  $21.7 \pm .83$  years, and the average height, weight and BMI were  $177.8 \pm 3.54$  (cm),  $65.0 \pm 6.45$  (kg) and  $18.3 \pm 1.8$  ( $\text{kg m}^{-2}$ ), respectively. This study protocol was approved before the start of this study by the Research Ethics Committee of the Central Regional Research Ethics Center, Taichung,

Taiwan. Written informed consent was obtained from each participant after detailed explanation of the study.

## **2.2 Experimental procedures**

Each participant attended three courses of training model and one course of simulation competition model. Each course started from 9 am and only one course was performed each day in order to enhance the credibility of this study. After the completion of the training models, the simulation competition was conducted.

### **2.3 Training model**

Brainwave activities of participants were recorded before performing each course of the training model in a quiet and resting state for 3 min, then recorded during the three courses of training models.

#### **2.3.1. Physical training course**

The electrical treadmills were used as physical training testing tools and the polar heart rate metre used to record heart rates. During the test, the running speed was fixed, and the slope adjustment was used to increase the intensity. The test method used incremental exercises with moderate intensity. The maximum heart rate was calculated as  $208 - 65 (.7 \times \text{age})$  (Tanaka, Monahan, & Seals, 2001), and the change of brainwaves was recorded during the whole process. When the heart rate reached  $100 \text{ min}^{-1}$ , the 30th–60th s brainwaves were recorded and calculated. Whenever the heart rate increased by 10, another 30th–60th s brainwave sequence was recorded and this pattern continued until the heart rate reached 150.

#### **2.3.2. Technical training course**

The participants were told to perform the specified kicking attacks to the speed target with the most rapid response while hearing the irregular whistle. During the process, the participants were not given any verbal suggestions until the completion of specified motor patterns. After the completion of all movements by the right foot, the left foot followed the same pattern. The sequence of kicking attacks was as follows: active attacks (such as roundhouse kicks), sliding roundhouse kicks, sliding side steps, axe kicks, counter-attacks (such as rear-leg roundhouse kicks), front-leg roundhouse kicks, front-leg side steps and front-leg axe kicks. Each course of movements was executed for 3 min. The brainwave was recorded throughout the whole course.

#### **2.3.3. Tactical training course**

The brainwave changes of the participants were individually recorded while watching the TKD competition film or cartoons. The brainwave was recorded starting from the moment the film was played. The duration of TKD competition was three rounds with 2 min each, for a total of 6 min. The coach then participated in the discussion of the competition film, and the recording time was 10 min. The funny cartoons were played for 10 min to compare the brainwaves during resting status with those during viewing of the two films.

## **2.4 Simulation competition model**

In the simulation games, we collected the brainwave signals from participants 1 min before three rounds of competitions. After the game was finished, the participants were divided into winner and the loser groups according to the result of the game. The differences of brainwave frequencies between the winner and the loser group were compared.

## **2.5 Electroencephalogram recording**

This study used NeuroSky Zigbee multiplayer synchronous brainwaves analyzer to measure EEG (RS232-DTE-3.0, Alchemy Technology Co., Ltd., Taiwan). NeuroSky Company developed brainwave headset technology based on an international 10–20 positioning system (Klem, Luders, Jasper, & Elger, 1999), which uses wireless single-point electrode technology to install a sensor on the left forehead, that detects and collects biological signals (brainwaves) generated by the thinking process of the brain and delivers the collected signals via real-time wireless Bluetooth transmission into the ThinkGear™ chip. The ThinkGear™ chip is responsible for filtering and removing the noise from original signals caused by environmental interference and the noise generated by muscle or pulse to improve the accuracy of the quantitative brainwaves. The useful signals were amplified through NeuroSky eSense™ patented algorithm interpretation, and finally, the quantitative parameters of brainwave frequencies from the International Organization of Societies for Electrophysiological Technology are used to categorise them into five frequency bands, including  $\delta$ ,  $\theta$ ,  $\alpha$ ,  $\beta$ ,  $\gamma$ . All these data of the area under the curve from five frequency bands were transmitted to a processing system for brainwave figures in a computer. Referring to previous studies (Clarke, Barry, McCarthy, & Selikowitz, 2001; Shi et al., 2012), the relative powers of EEG have been used to compare different groups. In this study, the brainwave state of participants was presented as relative percentages (%) by dividing the area under each frequency band curve to the total area of the five frequency band curves and multiplied by 100.

## **2.6 Statistical analysis**

The experimental test instruments interpreted the brainwave as eSense™ parameters by eSense™ patented algorithm. The statistical systems apply the software package of SPSS 12.0 for Windows to perform the statistical analysis, in which the data were expressed as means of a percentage  $\pm$  standard deviation. For repeated measures, ANOVA was used to analyse the technical, physical and tactical training programme modalities and compare these with the quiet resting state. For simulation games, paired sampling *t*-test was used to compare the difference between winner and loser groups at resting time of each round.

# **3. Results**

## **3.1 The brainwave changes in physical training course**

The percentage of  $\beta$ -wave was significantly increased when the heart rates of participants reached 120, 130, 140 and 150  $\text{min}^{-1}$  in comparison with the resting state, but other brainwave frequency bands showed no significant changes (Table 1).

**Table 1.** Effects of heart rates on the percentages of each brainwave frequency in the running process.

	$\delta$	$\theta$	$\alpha$	$\beta$	$\gamma$
Resting state	68.47 ± 6.56	15.56 ± 1.69	7.71 ± 1.91	5.15 ± 2.17	3.11 ± 1.34
HR100	63.28 ± 5.57	18.82 ± 2.62	9.16 ± 1.75	6.73 ± 1.47	2.67 ± 1.78
HR110	65.14 ± 7.15	16.02 ± 3.31	8.88 ± 1.43	7.97 ± 2.61	2.64 ± 1.33
HR120	63.88 ± 6.02	16.62 ± 3.09	9.23 ± 1.68	8.41 ± 1.19*	2.55 ± 1.22
HR130	66.06 ± 5.06	14.99 ± 1.92	9.13 ± 1.47	8.63 ± .94**	2.58 ± 1.42
HR140	65.59 ± 5.11	15.35 ± 2.82	8.91 ± 1.24	8.38 ± 1.27*	2.38 ± 1.11
HR150	64.29 ± 4.68	15.92 ± 1.68	8.87 ± 1.67	8.37 ± 1.05*	2.71 ± 1.11

HR: heart rate per min.

\*Indicates a significant difference compared to the resting state, \* $p < .05$ , \*\* $p < .01$ .

### 3.2 The brainwave changes in technical training course

Comparison of the five ( $\delta$ ,  $\theta$ ,  $\alpha$ ,  $\beta$ ,  $\gamma$ ) brainwave frequency bands between the resting state and kicking with the left or right foot indicated that the percentage of  $\gamma$ -wave was significantly decreased by right-foot ( $p < .01$ ) and left-foot kicking ( $p < .05$ ) (Table 2). There was no significant difference of brainwaves between left-foot and right-foot kicking.

### 3.3 The brainwave changes in tactical training course

While the participants watched the competition films and listened to the coach's comments,  $\gamma$ -wave was significantly increased when compared to both resting state and watching cartoons (Table 3). The other brainwave frequency bands showed no significant changes.

### 3.4 The brainwave changes in stimulation game

Before the second round of the game, the  $\delta$ -wave of the winner group was significantly increased when compared to that of the loser group, whereas  $\alpha$ - and  $\gamma$ -waves were significantly reduced (Table 4). When compared to the participants themselves, the  $\delta$ -wave of the winner group before the second round was significantly increased than that before the first round, whereas the  $\theta$ - and  $\alpha$ -waves were significantly reduced (Table 4). The  $\delta$  wave before the third round was significantly increased, whereas the  $\theta$ -wave was significantly decreased than those before the first round in the winner group. However, there were no significant changes in the loser group among these three time points.

## 4. Discussion

This study is the first report dealing with the changes of brainwave during training and competition processes of TKD. We found that (1) when the heart rate of participants reached 120–150  $\text{min}^{-1}$  during running, the  $\beta$ -wave was obviously increased; (2) the activity of

**Table 2.** Effects of right- and left-foot kicking on the percentages of each brainwave frequency.

	$\delta$	$\theta$	$\alpha$	$\beta$	$\gamma$
Resting state	64.52 ± 6.24	16.58 ± 1.75	7.89 ± 1.82	6.36 ± 2.25	4.65 ± 1.43
Right foot	66.87 ± 2.78	15.49 ± 1.54	7.94 ± .57	6.62 ± .56	3.26 ± .76**
Left foot	66.32 ± 3.02	15.47 ± 1.48	8.01 ± .69	6.72 ± .65	3.51 ± .60*

\*Indicates a significant difference compared to the resting state, \* $p < .05$ , \*\* $p < .01$ .

**Table 3.** Effects of watching competition and cartoon films on the percentages of each brainwave frequency.

	$\delta$	$\theta$	$\alpha$	$\beta$	$\gamma$
Resting state	64.77 $\pm$ 7.30	16.55 $\pm$ 3.05	8.03 $\pm$ 2.15	6.02 $\pm$ 1.91	4.58 $\pm$ 1.31
Cartoon film	60.56 $\pm$ 8.64	17.89 $\pm$ 2.22	9.59 $\pm$ 2.79	8.18 $\pm$ 3.41	4.62 $\pm$ 1.90
Competition film	55.46 $\pm$ 7.91	16.51 $\pm$ .83	8.86 $\pm$ 1.36	8.23 $\pm$ 3.14	8.69 $\pm$ 3.42 <sup>*,#</sup>

\*Indicates a significant difference compared to resting state, <sup>\*</sup> $p < .05$ .

#Indicates a significant difference compared to watching cartoon films, <sup>#</sup> $p < .05$ .

**Table 4.** Differences of the percentages of each brainwave frequency between winner and loser before each round of the stimulation game.

	$\delta$	$\theta$	$\alpha$	$\beta$	$\gamma$
Before the first round					
Winner	71.86 $\pm$ 3.71	14.31 $\pm$ 2.50	6.72 $\pm$ .63	5.05 $\pm$ 1.41	2.06 $\pm$ .82
Loser	74.84 $\pm$ 3.18	12.37 $\pm$ 1.51	6.12 $\pm$ 1.36	4.57 $\pm$ 1.17	2.11 $\pm$ .98
Before the second round					
Winner	75.75 $\pm$ 3.31 <sup>*,#</sup>	11.99 $\pm$ 1.78 <sup>#</sup>	5.81 $\pm$ .99 <sup>*,##</sup>	4.79 $\pm$ 1.24	1.68 $\pm$ .53 <sup>*</sup>
Loser	72.18 $\pm$ 3.88	13.18 $\pm$ 2.83	7.12 $\pm$ .87	5.11 $\pm$ .80	2.41 $\pm$ .79
Before the third round					
Winner	75.13 $\pm$ 4.87 <sup>##</sup>	10.99 $\pm$ 2.24 <sup>##</sup>	6.32 $\pm$ 1.33	5.61 $\pm$ 2.32	1.94 $\pm$ .68
Loser	73.23 $\pm$ 5.70	12.45 $\pm$ 2.72	6.56 $\pm$ 1.30	5.47 $\pm$ 2.07	2.28 $\pm$ 1.11

\*Indicates a significant difference compared to the loser at the same time point, <sup>\*</sup> $p < .05$ , <sup>\*\*</sup> $p < .01$ .

#Indicates a significant difference compared to themselves before the first round, <sup>#</sup> $p < .05$ , <sup>##</sup> $p < .01$ .

$\gamma$ -wave of the participants was significantly decreased in the process of kicking activities with either right or left foot; (3) when watching the competition film, the activity of  $\gamma$ -wave of the participants was significantly increased; (4) the  $\delta$ -waves of the winners were more active in a simulation game compared to that of the losers before the second round competition, and compared to the winners themselves before the first round. In contrast,  $\alpha$ - and  $\gamma$ -waves were significantly lower than those of the losers.

TKD is considered to be an open-skill exercise. The athletes have to observe the movements of the opponent, prepare the optimal attack timing, cope with the orders from the coach, and remain staying inside the bounds in a competition. Therefore, they require wider attention. Some researchers have pointed out that the cerebral cortex activities could be affected by attention and arousal levels during the information process and increased physical activities (Kamijo et al., 2004). Meanwhile, repeated training of TKD may form instinctive reactions of cerebellar activities, which could help the stability of movements and the speed of information process to form instinctive trends in both cognition and concentration (de Souza, Yehia, Sato, & Callan, 2013).

The result of this study showed that  $\beta$ -wave was increased significantly when the heart rate reaching 120–150  $\text{min}^{-1}$  during running exercises. Similar to this finding, significant enhancements of  $\beta$ -wave were found in some studies using bicycle dynamometer to perform high-intensity exercise and incremental intensity exercise (Schneider, Brummer, Abel, Askew, & Struder, 2009; Youngstedt, Dishman, Cureton, & Peacock, 1993). Youngstedt et al. (1993) observed that after acute exercises, although there were no correlated changes of body temperature and anxiety state, the brainwave activities of  $\beta$ -wave showed an upward

trend. In this study, we found no significant differences of  $\beta$ -wave during running before the heart rate reaching 120–150  $\text{min}^{-1}$ . However, when the heart rate of the participants exceeded 75–85% of the maximum heart rate in the process of high-intensity exercises, a decreased  $\beta$ -wave activity was reported when oxygen was lacking in the brain and blood flow (Kraaier, Van Huffelen, Wieneke, Van der Worp, & Bär, 1992). Fumoto et al. (2010) observed participants performing bicycle ergometer exercise for 15 min and found that  $\alpha$ -wave was significantly increased in the accelerating process of exercise. In our study,  $\alpha$ -wave showed an upward trend but no significant differences in the running exercise even though the heart rate reached 150  $\text{min}^{-1}$ .

The phenomenon of  $\gamma$ -wave reduction when hearing the whistles during kicking training in this experiment could result from the long-term TKD training these 12 participants had received. The participants may well accept the training pattern of kicking and do not need much attentional resource to form instinctive activities and  $\gamma$ -wave.

When participants watched the film of TKD competition and discussed this with coaches,  $\gamma$ -wave was significantly increased when compared to that of watching the cartoon film and the resting state. The activity of  $\gamma$ -wave reflects the association of selective attention between auditory and visual cortical areas (Fries, Reynolds, Rorie, & Desimone, 2001; Marshall, Molle, & Bartsch, 1996; Plourde et al., 2008). Fries et al. (2001) gave visual stimulus to monkeys and found a  $\gamma$ -wave enhancement in the condition of selective attention and ignorance of the associated stimulus. In our study, participants have to pay attention to the stimulus given by the coaches regarding the tips of advantages and disadvantages of movement control from the contestants in the film. Therefore, the  $\gamma$ -wave enhancement may reflect the instinctive attention of participants to the auditory stimulus given by the coach.

We found that  $\delta$ -wave of the winners at 30 s before the second round was more active than the losers, whereas  $\alpha$ - and  $\gamma$ -waves were less active than the losers. Kirmizi-Alsan et al. (2006) also reported the enhancement of  $\delta$ -wave in the frontal lobe when there's a need to maintain a certain degree of efficient concentration during a continuous performance task in 24 participants. Previous studies (Fontana, Mazzardo, Mokgothu, Furtado, & Gallagher, 2009; Hepler & Feltz, 2012) had commented that the quality and speed of decision in the competition were major factors affecting the performance. The strategic decision is based on the exercise skill and combined with the current situation in the competition and the past experience. In real competition, the coach and the contestant are required to determine the offensive or defensive strategy for the next round during the rest time. Therefore, the active  $\delta$ -wave of the winners may reflect that the contestants have better confidence about the decision of offensive and defensive plan before the second round. It may indicate that the physical arousal level of the winner is lower before the next round of competition. The results of this experiment indicated that before the beginning of next round TKD competition, the coach should quickly prepare the strategic plan based on the opponents' habits and give the order, and the contestants should maintain a status of stable emotion.

There are limitations in this study. First, the brainwave activity status was not completely recorded during simulation games. Unlike those closed-skill exercises, TKD is a physical collision exercise and cannot be evaluated or predicted in competition. Stronger and lighter designs are required for further study. Second, there were only 12 participants and all males who were all teammates and familiar with each other. Therefore, the status of brainwaves could be affected and leading to the result of no significant difference between two parties before the competition.

In conclusion, we reported factors affecting the results of TKD competition, which can help coaches build up strategic plans for training. Larger scale study populations are needed for further evaluating the brain activities during competition of TKD.

## Conflicts of interest

All authors declare no conflicts of interests.

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