

The biomarkers of brain activity, physiology and biomechanics in cycling performance: A literature review

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ABSTRACT

Generally, in sports performance, the relationship between movement science and physiological function has been conducted integrating neuronal mechanism over the past decades. However, understanding those interaction between neural network and motor performance comprehensively in achieving optimal performance mainly in cycling is still lacking. The purpose of this study was to discuss the issues in neuroscience related to brain activity, physiological and biomechanics in achieving optimal performance in cycling. As sports technology improves, more objective measurement can be demonstrated in solving specific issue in cycling. In this review, the focus on brain activity will be based on the evaluation of alpha and beta brainwaves as well as the alpha/beta ratio. Understanding of the mechanism and interaction between brain activity, physiology and biomechanics in competitive cycling will be acquired. Moreover, the biomarkers of brain activity related to cycling performance from previous studies will be identified and discussed.

INTRODUCTION

As athletes, coaches, trainers and professionals aim on what makes a difference between winning and losing, the emerging field of sports neuroscience seeks to produce better understanding between brain and behavior (Park *et al.*, 2015). According to Yarrow *et al.* (2009), apart from physical fitness, elite athletes must develop sport specific cognitive skills that integrate with perception, cognition and action. When talking about competitive cycling, especially during high-pressurized situations, brain function plays an important role in regulating physiological and biomechanical functions (Cheron *et al.*, 2016). These interactions are present in the mechanism involving brain imaging from a neuroscience perspective. *Exercise* functions in cycling are prominently explored and investigated using variables such as maximum oxygen consumption (VO₂max), power (Ludyga *et al.*, 2016b), and blood lactate (Hottenrott *et al.*, 2013). Since cycling is considered a continuous cyclic movement due to pedalling, researchers have recently started to investigate how brain activity was influenced and changed with cadence (Ludyga *et al.* 2016a; Ludyga *et al.*, 2016b; Ludyga *et al.* 2016). It involved the mechanisms of brain activity as well as physiological and biomechanical functions that have been thought as the activation of motor units signalling from the central nervous system (Ludyga *et al.*, 2016). This area of study was found to be limited in sports applications and thus even more lacking in cycling. This was due to the methodological limitations in solving brain function issues especially in more dynamic movements (Brümmner *et al.*, 2011). Therefore, the focus of this review was to discuss the issues in neuroscience in the context of brain activity interactions with physiological and biomechanical functions in achieving optimal performance in cycling. Additionally, the common methodological issues in brain activity and EEG biomarkers related to cycling performance will also be discussed.

INTERACTION BETWEEN BRAIN ACTIVITY, PHYSIOLOGICAL FUNCTIONS AND BIOMECHANICAL MECHANISMS

Neurophysiology is the term much utilized in exploring relationship between brain activity and physiology. It expresses the link between multiple signal neurophysiologic from different neural generators at different brain regions. It is often related to the neuron's ability to adapt to training and exercise which consequently leads to neural efficiency (Ludyga *et al.*, 2016b). Individuals who possess neural efficiency are thought to have high cognitive task due to increased proficiency in brain cortical function (Neubauer & Fink, 2009). It was evident that pedalling with high intensity during training can prolong cycling performance and contribute to maximal aerobic power (Hottenrott *et al.*, 2013). Additionally, the different level of athletes' competitiveness, which was affected by their individual training levels and participation in competition, caused variation in their brain function activity (Nakata *et al.*, 2010).

On another note, research has been conducted by Tytell *et al.* (2011) with their aim of discovering the link between brain activity and biomechanical mechanism. They found that interaction between the two comprised elements of neural circuits, muscles, environment and body. The body itself represents the motor output in which the movement was executed. According to Li (2004), he discovered that cycling movement controlled by the central nervous system would influence neuromuscular control to regulate the body's postures and pedalling cadence. This connection between the central nervous system and neuromuscular control was due to the presence of signals from the sensory stimulus which is required before the movement could be executed. Furthermore, the same researchers explained that the interactions between neural circuits, body, muscles and environment are crucial to understand despite it being difficult to predict (Tytell *et al.*, 2011).

Based on the nature of cycling, physiological variables of a well-trained cyclist with three to five years of training for 60-240 minutes a day should possess 70-75 ml/kg/min or 5.0-5.3 L/min of VO₂max and 300-450 power output (Jeukendrup et al., 2000). In order to obtain optimal physiological function, specific training is required to improve the athlete's performance. As far as mechanical efficiency is concern, particularly in cycling, the biomechanical application is critical. In competitive cycling, power output becomes an indicator of mechanical efficiency to determine cyclist performance during training which eventually predicts their physiological performance (Reed et al., 2016). Therefore, recent issues on how these functions can influence brain activity is highly in demand. In a high-pressurized situation especially during competition, athletes require high central activation to maintain and sustain high loads (Bailey et al., 2008). Consequently, a decreases of central activation often leads to fatigue and subsequently poor performance since it is related to brain function central mechanism (Timothy D. Noakes, 2012). Previous findings have confirmed that in endurance competitions, the maintenance of a high central activation is required to prevent the reduction of power output and the termination of exercise resulting from central fatigue (Shober & Schumann, 1991) as cited in Ludyga et al. (2016a).

METHODOLOGICAL ISSUES IN STUDIES ON BRAIN ACTIVITY

The methodological issues in studies on brain activity in sports application have been highlighted since a decade ago (Thompson et al., 2008). Investigations of brain activity have transformed from using high cost equipment with limited feasibility in resolving rapid variations of activity (Enders et al., 2016), such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) (Brümmer et al., 2011), to the use of electroencephalographic (EEG) recording which is cheaper, easy to wear, lightweight and has high temporal resolution (Reis et al., 2014). The EEG is also known for its non-invasive nature of high density recording in providing quantitative feedback to practitioners and coaches (Chapman et al., 2008; Cheron et al., 2016; Lopes da Silva, 2010; Reis et al., 2014; Thompson et al., 2008). However, for application in sports setting, there is still a need for improved hardware and software that are able to minimize artifacts. The artifacts that potentially occur are muscle artifact, skin artifact, electrode movement, eye movement, ECG artifact, respiration artifact, tongue movement, electrical interference, and restriction of mobility (Thompson et al., 2008).

The use of EEG in sporting research, either in the context of exercise or for competitive purposes, has always been more dominant among less dynamic sports. Less dynamic movement during locomotion, such as static or cyclic motion, was found to be able to minimize artifacts. In fact, these type of movements enable research to be conducted in the lab setting. However, recent development in mobile EEG technology provides an opportunity in tackling many issues related to neuroscience and sporting behavior despite having challenges to move out from the lab (Park et al., 2015).

THE BIOMARKERS OF EEG RELATED TO CYCLING PERFORMANCE

Table 1 The biomarkers of EEG related to cycling

Brainwaves	Previous study	Variables	Corresponding function
Alpha/beta ratio	(Ludyga et al., 2016)	Effects of high cadence	Vigilance
alpha/beta ratio	(Ludyga et al., 2016b)	High vs low aerobic power	Neural efficiency
Alpha, beta	(Ludyga, et al., 2016a)	High versus low cadence upon aerobic	Sensorimotor processing, arousal

performance			
Alpha, beta, gamma	(Enders et al., 2016)	High intensity cycling exercise	Fatigue, motor control
Beta	(Jain et al., 2013)	Pedaling	Sensorimotor processing
Alpha, beta	(Hottenrott et al., 2013)	Cadence and relationship with heart rate, blood lactate and RPE	Fatigue
Alpha, beta	(Comani et al., 2014)	Attentional focus, optimal performance	Arousal, attentional focus, motor commands

In this part, it is the author's intention to discuss the issues of EEG biomarkers related to cycling performance. As previously mentioned, studies on application of sports neuroscience in more dynamic natured sports are still rare. A previous study had summarized five major EEG biomarkers based on type of brainwaves which are delta, theta, alpha, beta, gamma (Cheron et al., 2016). For the purpose of this review, only biomarkers of EEG specifically for cycling performance was highlighted. Based on Table 1, most studies conducted on brain activity in cycling context are based on alpha and beta waves as well as alpha/beta ratio. Therefore, the discussion will emphasize on these two brainwaves and their ratio. These brainwaves mostly focused on basic movement in cycling in which cyclists have to pedal to move the bicycle. When a cyclist is pedalling, all reactions and mechanisms from the human physiological and biomechanical aspects as well as brain activity are involved.

There is contradicting finding on the effect between low cadence training and high cadence training among cyclist. The brain cortical activity showed changes in the frontal area for low cadence training at baseline and after the intervention. On the other hand, for high cadence training, the alph/beta ratio did not show changes after the intervention period. This demonstrated that exercising at high pedalling frequencies allowed cyclists to complete similar load with less brain cortical activity. Consequently, this leads to neural efficiency which ensures reservation of cortical resources for prolong workloads (Ludyga et al., 2016).

It has been supported by the other study which stated that reducing alpha and overall spectral power will produce similar improvements in aerobic power for low and high cadence training. However, high cadence training could prepare cyclists to maintain high performance in endurance. In addition, it can also improve the central and peripheral adaptations delaying fatigue among cyclists (Ludyga et al., 2016a).

Compared to resting state, the alpha/beta ratio decreases during cycling exercise as beta power increases more than alpha power (Ludyga et al., 2016b). Increased beta activity reflects higher cortical activation which might be the result of greater processing demands during exercise and the tendency of the sensorimotor system to maintain the network (Engel & Fries, 2010). As alpha power serve as an inverse indicator of mental alertness or arousal, it can be assumed that a lower level of arousal at rest is due to greater relaxation ability in subjects with higher maximal oxygen consumption (VO₂max) (Nielsen, Hyldig, Bidstrup, González-Alonso, & Christoffersen, 2001). It was supported by Jacobs (2001) who further explained about beta power with high cadence training will decrease as a response of EEG to relaxation.

High cortical activation is necessary to provide high performance and power output in cycling. As explained by Noakes (2011), cycling performance is controlled by the central nervous system regulatory mechanism. This control mechanism does not restrict the functions of the heart or skeletal muscles but it regulates the power output by controlling the number of recruited muscle fibres or motor units involved in the working muscles. Training at different cadences seems to be the key to respond to different requirement during a race. In

order to increase power output at higher cadences, higher cortical brain activation is necessary (Hottenrott et al., 2013).

While most researchers focused on changes in brain activity caused by movement in cycling, one group of researchers conducted a study on how different attention could change cyclist's brain activity (Comani et al., 2014). The study proved that the right attentional focus can determine optimal performance during high-fatigue or stressful situation. They claimed that when cyclists focused on the external environment, it would lead to superior performance.

The results of EEG coherence of the alpha beta band showed that the alpha band indicates lower arousal state and are accompanied with higher alpha power eventually required in goal-directed behavior. It was further explained that it is related to attentional focus on the components of action and the feeling of muscle fatigue. On the other hand, the beta band from this study indicates that there is an involvement with sensorimotor processing that is associated with resistance to movement, voluntary action as well as emotional capacity in coping with fatigue. Thus, future researchers may look into different sports as they may require different attentional focus during competition. Apart from that, there is also a need to study the physiological and biomechanical influence towards a cyclist's attentional focus that may potentially lead to neural efficiency.

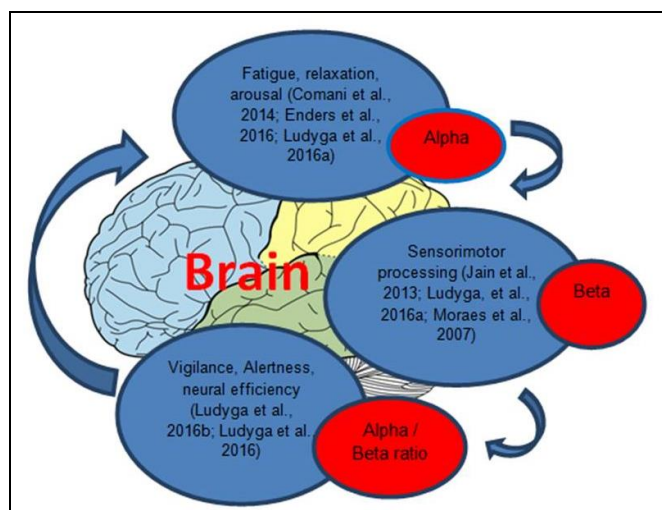


Fig. 1 EEG Biomarkers and its corresponding function of cycling

Based on previous studies, this review came out with a simple framework to present potential EEG biomarkers and its corresponding function with regards to cycling performance and exercise. According to Fig. 1, the alpha and beta brainwaves along with the alpha/beta ratio play important roles in identifying the mechanism of cyclists' physiological functions and required movement to achieve optimal performance. Nevertheless, this framework is limited to studies shown in Table 1. Therefore, it is essential to form such adaptation from theoretical aspects in determining mutually defined terms towards specific physiological and biomechanical perspectives. Furthermore, identification from specific brain region is also critical as it differs from each other in terms of its function.

CONCLUSION

There is a lot of areas in relation to brain activity that can significantly contribute to improvement of cycling performance as well as in reaching peak performance. Generally, the methodology used in future studies should also attempt to minimize artifacts and possible noise. Specifically to cycling performance, current researches have highlighted physiological function and basic movements in cycling. However, whether it is critical to the outcome of a race, there is a great need to identify what makes a difference between a winner

and a loser. At resting state, trained and untrained athletes have different EEG rhythms (Del Percio et al., 2009), consequently may suggest individual difference of potential.

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