

## **INTEGRATION OF BRAIN ACTIVITY, NEUROPHYSIOLOGY AND NEUROMECHANICS IN CYCLING PERFORMANCE: A CONCEPTUAL FRAMEWORK**

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### **Abstract**

Neuroscience is a discipline in cycling performance that has become increasingly significant as its methodologies have developed and progressed. The methodological approach incorporated with technological advancements such as electroencephalogram (EEG) contributes to vast novelty in the area of sports neuroscience. As the nature of cycling performance works much with human and mechanical components associated with cardiovascular function and muscular force production, it directly involves the elements of neurophysiology and neuromechanics in applying sports science towards cycling performances. The integration of these two sub-disciplines of neuroscience is connected with brain activity function. Therefore, the authors aimed to develop a conceptual framework integrating brain activity into a physiological and biomechanical function primarily for cycling performance. This conceptual framework will offer a direction for future studies related to brain activity, neurophysiology and neuromechanics.

**Keywords:** Cycling, brain activity, neurophysiology, neuromechanics

## **Introduction**

This paper intends to highlight the issues in sports neuroscience, focusing on cycling performance. Neuroscience is a rigorous area of study which is able to increase the attention of researchers incredibly towards incorporating neural activity with human biological, physiological, human movement and psychological criteria (Cheron, 2015; Cheron et al., 2016; Lewthwaite & Wulf, 2010). The multidiscipline nature of neuroscience cater to issues related to cycling performance. As the nature of road cycling competition includes being exposed to different environments, as well as dealing with mechanical efficiency for a long distance and duration (G Atkinson, Davison, Jeukendrup, & Passfield, 2003; Davies et al., 2016), it is acknowledged that optimal cycling performance is dependent on pacing strategy, as it reflects on the brain's regulation of body homeostasis. As a consequence, this condition has been closely related to neural activity from central nervous system linked to the brain. The emergence of this area was due to advances in technology that have allowed research in cognitive neuroscience to contribute to the discipline of sport psychology (Holmes & Wright, 2017). After all, the mechanism of connection from central nervous system and peripheral nervous system open for further exploration towards integration of brain activity with physiological and mechanical perspectives. Research and applications in this area have been widely published for other sport and exercise settings as well (Bianco, Berchicci, Perri, Quinzi, & Di Russo, 2017; He et al., 2018; Ivaldi, Cugliari, Fiorenti, & Rainoldi, 2018; Ivaldi, Pretari, & Cugliari, 2018; Masaki, Maruo, Meyer, & Hajcak, 2017; Pereira, Argelaguet, Millán, & Lécuyer, 2018; Powers, Hastie, & Tibshirani, 2018; Van den Berg, Coetsee, Blijnaut, & Mearns, 2018). However, the focus of this paper concerns cycling performance and exercise related to cycling.

## **Brain activity**

The electroencephalogram (EEG) can be used as a tool in studying electrical brain activity to understand the process of performing specific skills (Thompson, Steffert, Ros, Leach, & Gruzelier, 2008). Highly-skilled athletes would normally perform with minimal effort compared to novices, as directed by the concept of economy from the brain activity, with an inverse relationship between optimal performance and consumption of resources (Bertollo et al., 2016). In sports sciences, this mechanism is recognized as neural efficiency. In terms of cycling performance, cyclists with a higher levels of neural efficiency indicated low activation of cortical activity as compared to less neural efficient cyclists. Based on a study conducted by Ludyga, Gronwald, & Hottenrott (2016), cyclists with high level of maximum oxygen consumption (VO<sub>2</sub>max) showed less cortical activity due to inhibition of task-irrelevant cognitive processes. A few other researches have indicated a similar mechanism of neural efficiency with respect to sports performance (Bertollo et al., 2016; Di Fronso et al., 2016; Ludyga, Gronwald, & Hottenrott, 2016a).

Imagery practice on the other hand, which is commonly applied throughout various sports to enhance performance, can be better understood through the mirror neuron system. This system works when there is an activation from mirror neurons in the premotor and posterior parietal cortex during observation of similar action performed by others

(Thompson et al., 2008). This proves that brain activity function can be used as an objective measure in the field of sport psychology as the study is focused on decision making and strategic planning during competition. It has been closely related to issues in cycling performance, since brain activity function is required in regulating the right pace throughout an entire race (Greg Atkinson, Peacock, Gibson, & Tucker, 2007; Corbett, Barwood, Ouzounoglou, Thelwell, & Dicks, 2012; Davies et al., 2016; Mauger, Jones, & Williams, 2009; Micklewright, Papadopoulou, Swart, & Noakes, 2010; Pinheiro, Santos, & Pires, 2016; Stone, Thomas, Wilkinson, Gibson, & Thompson, 2011; Whitehead et al., 2017; Williams et al., 2015). However, there has been no study that has related decision making and strategic planning with neural efficiency and intelligence objectively. The only available resource to correlate between decision making and intelligence were from the theory of terminology as decision making is understand as reasoning and making thought in which it defined within intelligence characterization (Neubauer & Fink, 2009). After all, during competition, whatever definition decision making and intelligence take, both contribute towards making the right decisions in pacing strategy. This happen especially in the nature of cycling competition where opponents exist and behave accordingly, the cyclist needs to react and respond on their pace that leading to decision-making process (Konings & Hettinga, 2018).

## **Neurophysiology**

The core component integrated with human performance is comprised of general mechanisms of neurophysiology which specifically involve brain activity (Del et al., 2009; Mothes et al., 2017). The physiology of the human system includes the increase of force production by the heart and skeletal muscles. For instance, endurance cyclists are required to pedal fast over long distances so that the heart becomes compliant, enabling it to accommodate a lot of blood to generate a larger stroke volume (Noakes, 2011). Thus, the interaction between cardiovascular function and muscular force production is the primary evaluation of physiological function in sports and exercise in general. On the other hand, when using neurophysiology to interpret total human performance function, there is the additional role of brain activity that may cause either termination or optimization of performance in sports and exercise.

In cycling performance, the main indicators of physiological function are maximum oxygen consumption ( $VO_{2max}$ ) (González-Haro, Galilea, & Escanero, 2008; Hawley & Noakes, 1992; Lamberts et al., 2009; Nielsen, Hyldig, Bidstrup, González-Alonso, & Christoffersen, 2001), blood lactate (Padilla, Mujika, Orbañanos, & Angulo, 2000; Razanskas, Verikas, Olsson, & Viberg, 2015; Sayers, Twedde, Every, & Wiegand, 2012), power output (Greg Atkinson et al., 2007; Balmer, Davison, & Bird, 2000; Jeukendrup, Craig, & Hawley, 2000; Padilla et al., 2000), cadence (Diefenthaler, Coyle, Bini, Carpes, & Vaz, 2012; Lucía, Hoyos, & Chicharro, 2001; McGhie & Ettema, 2011; Reed, Scarf, Jobson, & Passfield, 2016), and heart rate (Hue, Chamari, Damiani, Blonc, & Hertogh, 2007; Palomo & Rodríguez-marroyo, 2014; Stone et al., 2011). The importance of having high level of physical fitness in order to optimize sports performance is mutually understood. Studies on the integration of brain activity in formulating individuals to be superior to their competitors is much needed since it would boost optimization of

performance while fulfilling theories previously developed by scholars. It has been recently touched by scholar on the connection of brain activation with musculoskeletal system that controlled within central nervous system, as this is important in regulating central fatigue and peripheral fatigue (Perrey & Besson, 2018).

## **Neuromechanics**

There is a growing amount of studies on neuromechanics in the area of sports performance and rehabilitation. Electroencephalogram (EEG) has been recognized as a non-invasive measurement tool for brain imaging and has been used to record cognitive tasks during locomotion (Gwin, Gramann, Makeig, & Ferris, 2010). This emerging field is not limited to sports since a number of researchers are looking for significant interaction between brain activity and human mechanical properties ((Bini, Diefenthaler, & Mota, 2010; Hug & Dorel, 2009; Ludyga, Hottenrott, & Gronwald, 2016; Schneider, Rouffet, & Billaut, 2013). As cycling performance is much more likely to be influenced by technical applications such as body mechanics in order to maximize efficiency, especially when dealing with drag force, it is important to look into the specific mechanisms of brain activity after considering that biomechanics of the muscle, body and environment as neural circuits do not function independently. In fact, the human mechanical adaptation assisting cyclists during training showed improved coordination and increased neural drive during maximal muscle contraction (Nybo & Secher, 2004).

The brain region responsible for planning or programming cyclists' mechanical movement is the frontal cortex. There is important scientific evidence of neural activity within athletes' brains and how they interact with the physical world (Tytell, Holmes, & Cohen, 2011). The priority of neuroscience is to ensure that interactions between human systems respond to the external environment to produce performance outcome. Before performance outcomes can be indicated, the desired behavior that implies movement should be linked with the mechanical system that comprised muscles, mechanical body and environment. However, this interaction is extremely complex as it requires analysis of brain activity, body mechanics and environment in which the movement is executed (Tytell et al., 2011).

In cycling performance, studies in the field of neuromechanics have been carried out. There are studies on basic movement looking at the interaction between neural activity and pedaling technique (Ludyga, Hottenrott, et al., 2016) as well as studies trying to find the significance of muscle output in affecting cycling performance (Dingwell, Joubert, Diefenthaler, & Trinity, 2008). However, those studies do not evaluate elements of kinetic or kinematic quantity that enables specific observation of biomechanical interactions with brain activity, despite it being necessary in resolving the determinants of exercise performance (Perrey & Besson, 2018). This gives evidence for the emerging and growing interest towards interaction of brain activity and human mechanical elements. Many other areas can also be explored particularly in mechanical system such as how body react to perturbation (Gwin et al., 2010) as far as rehabilitation is concern. It is also important and significant to understand neuromechanics in order to return the cyclist back to their optimal performance after recovering from injury. In addition, one study found

that extreme environments potentially affect cyclists' cognition and biological functions (Taylor, Watkins, Marshall, Dascombe, & Foster, 2015). Hence, all sensory stimulus contributing to resultant performance ideally should be studied by neuroscientists and biomechanicians.

### **Conceptual framework for future study**

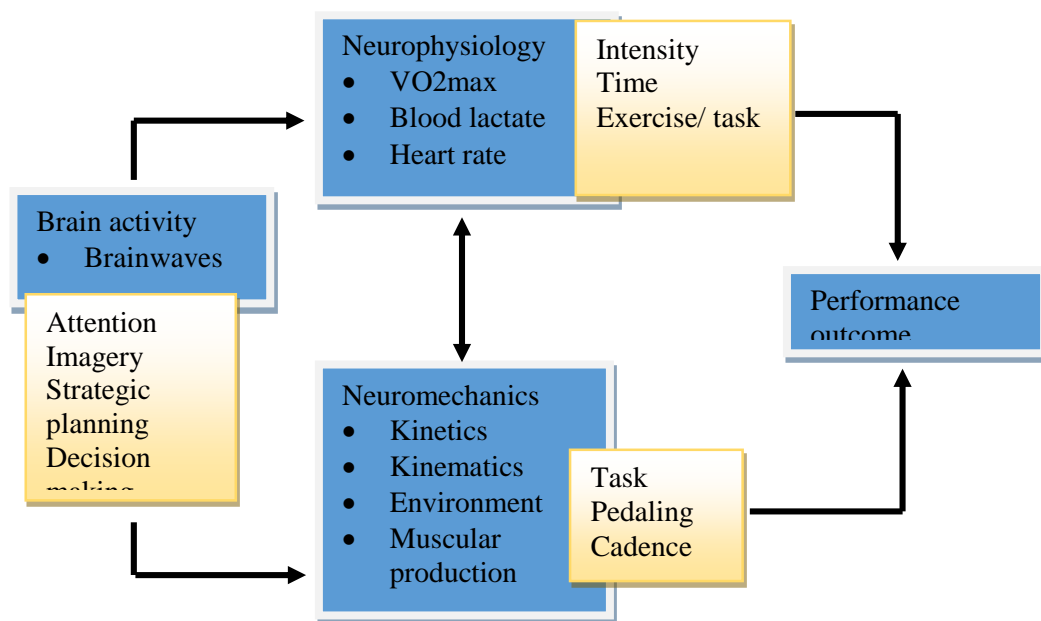
A review of previous study specifically in cycling and exercise performance has been discussed by previous scholars (Zainuddin, Omar, Zulkapri, Jamaludin, & Miswan, 2017). In the review (table 1), it helps to give clearer point of view on the evaluation of growing this field. Although it was focus on the EEG frequency of brain activity (as it dominant), it was relevant tool as it could revealed real time of temporal resolution in which it significant in sport setting especially cycling performance. Although it does not classify specifically on the area of neurophysiology and neuromechanics, the explanation from this subtopic above are related to the brief description from the table. This study will contribute a conceptual framework that is based on the integration of brain activity, neurophysiology and neuromechanics with focus on cycling performance. When studying brain activity in dynamic motion, researchers need to identify a methodology for measuring real time movement.

**Table 1:** Brain Activity of cycling exercise and performance

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 performance	Sensorimotor processing, arousal
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, Taubert, & Gronwald, 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
Beta	(De Pauw et al., 2013)	Prolong cycling, recovery	Sensorimotor processing, fatigue,
Alpha	(Robertson & Marino, 2015)	Exhaustion	Arousal, attention

Source: (Zainuddin et al., 2017)

Currently, the most appropriate tool is EEG, as it can be precisely timed at a speed faster than the speed of human thought and action (Gramann, Ferris, Gwin, & Makeig, 2014). Nevertheless, the nature of the EEG device that is prone to noise leading to amplitudes with magnitudes larger than that underlying the human brain; this will slow down research activity related to the application of neuroscience in sports. Investigation is still under development by removing mechanical artifacts (Gwin et al., 2010). However, there has been a growing number of methodological approaches attempting to minimize the artifacts that contribute to real time investigation using EEG (Cheron et al., 2016; Gramann et al., 2014; Rattray, Smale, Northey, Smees, & Versey, 2017; Reis, Hebenstreit, Gabsteiger, von Tscharnner, & Lochmann, 2014). At present, research activity on brain activity and physiology has been conducted intensely (Cheron et al., 2016), including studies on cycling performance where in which a well-trained cyclist becomes the subject of study. This was also supported at the very recent review about the integration of these three fields of brain activity, neurophysiology and neuromechanics (Ouvrard et al., 2018; Perrey & Besson, 2018).



**Figure 1:** Conceptual framework of cycling performance

The area of study ranges from attentional focus to aerobic exercise to optimal pedaling rate. Therefore, this study proposed a conceptual framework to fill the missing link between brain activity and performance described as behavior (Tytell et al., 2011). The missing links are the neurophysiological and neuromechanical functions which will provide better understanding towards neural activity of central nervous system corresponding to the cyclist's individual resources. As far as integration between these three elements (brain activity, neurophysiology, neuromechanics) is concern, isolating any one of them might cause stagnant research activity on optimal performance at high level of competition. This has been supported and emphasized in the model of involvement brain in the exercise physiology by Noakes (2011). The author stated that the brain function

sustains more distance, although heart capacity received a signal to stop the exercise. Thus, in appreciating all mechanical and physiological elements predominantly in cycling, the conceptual framework theoretically contributes to realignment and development in the direction of neuroscience perspective.

## **Conclusion**

In summary, the integration of brain activity, neurophysiology and neuromechanics show great promise and progress. Based on the discussion above, the study of neuromechanics related to cycling performance is relatively new. However, the importance to clarify such behavior in terms of performance outcomes which are relevant to predict which sensory stimuli are pertinent to neural circuit and what motor output produces applicable movements. In fact, in the field of neurophysiology, some scholars have produced scientific results demonstrating the interaction of specific muscle contraction with neural activity of specific brain region. It is difficult to isolate physiological and biomechanical functions as far as optimal cycling performance is concerned since muscular force production is influenced by the environment and regulated by the neuromuscular and cardiovascular system working simultaneously. Researchers should not neglect the central nervous system, as brain activity is the main utility for sensory, input and output of human movement.

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