TASK DIFFICULTY TOOLS TO ANALYZE COGNITIVE PERFORMANCE AND NEURAL EFFICIENCY FOR CYCLIST IN VIRTUAL REALITY

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DEDICATION

This thesis is dedicated to my parents, family, friends and those knowing me that taught the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to them, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

Task difficulty modulates neural activity as individuals with high neural efficiency are associated with high cognitive performance in demanding tasks. In road cycling, this event inherently deals with uncertain environments as cyclists need to respond with competitors' action, varied terrains, and environments. However, assessing the interaction between cognitive performance, task difficulty and neural efficiency require the development of sport-specific tasks in road cycling. Therefore, the purpose of this study is to evaluate the association between cognitive performance, task difficulty, neural efficiency, and physiological functions of road cycling. Prior to that, the experimental procedure development of task difficulty in the virtual reality was modified according to the content by experts and feedback from healthy subjects. The actual experiment was conducted on twelve trained development cyclists from the National Sports School. Parameters of brain activity were set with frequencies of 8–12Hz for α waves and 15–28Hz for β waves and were measured using electroencephalography (EEG) bioamplifiers. Physiological parameters of power output, heart rate and cadence were measured using Garmin's pedal force sensor, heart rate monitor and cadence sensor. The independent sample *t*-test was employed to compare between High-IQ and Low-IQ groups across all parameters. The one-way repeated measure ANOVA was used to further analysed the physiological functions of High-IQ and Low-IQ groups during different task difficulties. The results of the independent sample *t*-test showed that the High-IQ group is significantly higher in neural efficiency than the Low-IQ group during medium difficulty tasks (level 3), $t(7.23)=3.33$, $p<0.01$. Furthermore, results from the one-way repeated measure ANOVA revealed interactions between task difficulty and cognitive performance were significant as the main effects on neural efficiency $F(4,40)=4.728$, $p=0.009$. The main contribution of this study is the exhibition of the High-IQ group performed high neural efficiency compared to Low-IQ groups during a medium level of task difficulty (level 3). The significance between 1 to 2km showed the changes in cortical activation and sensorimotor processing. It suggests the sensorimotor condition for High-IQ group modulation occur during the last 1km. In Task 3, this study added competitors as there is a possibility that the subjects respond to the environments, including the presence of competitors. In conclusion, cognitive performance is associated with α/β ratios that describe neural efficiency during the different levels of task difficulties in road cycling among trained development cyclists. Future research may consider increasing the level of competitors or increasing the number of competitors as a potential element of difficulty.

ABSTRAK

Kesukaran tugasan memodulasi aktiviti saraf kerana individu dengan kecekapan saraf yang tinggi dikaitkan dengan kecerdasan kognitif yang tinggi ketika melakukan tugasan yang mencabar. Dalam aktiviti berbasikal lebuhraya, ianya dikaitkan dengan persekitaran yang tidak menentu kerana atlet berbasikal perlu bertindak balas dengan tindakan pesaing, serta persekitaran yang berbeza-beza. Walau bagaimanapun, menilai interaksi antara prestasi kognitif, kesukaran tugasan dan kecekapan saraf memerlukan situasi tugasan yang khusus dalam sukan berbasikal lebuhraya. Oleh itu, kajian ini bertujuan untuk menilai hubungan antara prestasi kognitif, kesukaran tugasan, kecekapan saraf, dan fungsi fisiologi berbasikal lebuhraya. Sebelum itu, prosedur eksperimen untuk kesukaran tugasan di persekitaran VR diubah mengikut maklum balas oleh pakar dan dari penilaian subjek yang sihat. Eksperimen sebenar dijalankan ke atas dua belas atlet berbasikal muda yang terlatih dari Sekolah Sukan Negara. Parameter aktiviti otak ditetapkan dengan frekuensi 8–12 Hz untuk gelombang α dan 15–28 Hz untuk gelombang β. Ia diukur menggunakan bioamplifier elektroensefalografi (EEG). Parameter fisiologi daya kuasa, denyutan jantung dan kadens diukur menggunakan penderia kekuatan pedal Garmin, alat pengesan denyutan jantung dan penderia kadens. Ujian bebas *t* sampel digunakan untuk membandingkan antara kumpulan IQ tinggi dan IQ rendah di semua parameter. Pengukuran berulang sehala ANOVA dianalisis lebih lanjut terhadap kumpulan IQ tinggi dan IQ rendah untuk fungsi fisiologi semasa kesukaran tugas yang berbeza. Hasil ujian bebas *t* sampel mendapati bahawa kumpulan IQ tinggi lebih tinggi secara signifikan dalam kecekapan saraf daripada kumpulan IQ rendah semasa tugas kesukaran sederhana (tahap 3), $t(7.23)=3.33$, $p<0.01$. Selanjutnya, hasil pengukuran berulang sehala ANOVA mendedahkan interaksi antara kesukaran tugasan dan prestasi kognitif adalah signifikan sebagai kesan utama terhadap kecekapan saraf $F(4,40)=4.728$, $p=0.009$. Sumbangan utama dari kajian ini menunjukkan kumpulan IQ tinggi melakukan kecekapan saraf tinggi berbanding kumpulan IQ rendah semasa tahap kesukaran tugasan sederhana (tahap 3). Berdasarkan hasilnya, kepentingan antara jarak 1 hingga 2km menunjukkan perubahan pengaktifan kortikal dan pemprosesan sensorimotor. Ini menunjukkan keadaan sensorimotor untuk modulasi kumpulan IQ tinggi terkesan dalam 1km terakhir. Dalam Tugasan 3, kami menambah pesaing kerana ada kemungkinan subjek bertindak balas terhadap persekitaran. Kesimpulannya, prestasi kognitif dikaitkan dengan nisbah α/β yang menggambarkan kecekapan saraf semasa menjalankan tugasan dengan tahap kesukaran yang berbeza dalam berbasikal lebuhraya di kalangan atlet berbasikal muda yang terlatih. Penyelidikan masa hadapan boleh mempertimbangkan untuk meningkatkan jumlah pesaing dan faktor-faktor yang berpotensi menjadikan sesuatu tugasan semakin sukar.

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LIST OF ABBREVIATIONS

VR	-	Virtual Reality
IQ	-	Intelligence Quotient
Raven’s SPM	-	Raven Standard Progressive Matrices
EEG	-	Electroencephalogram
fMRI	-	functional Magnetic Resonance Imaging
fNIRS	-	functional near-infrared spectroscopy
ERD	-	event-related desynchronisation
ERS	-	event-related synchronisation
IAPF	-	alpha peak frequency
VO2max	-	maximum oxygen consumption
CNS	-	central nervous system
PNS	-	peripheral nervous system
HMD	-	head mounted display
CAVE	-	cave automatic virtual environment
FFT	-	fast fourier transform

LIST OF SYMBOLS

gf	-	Fluid Intelligence
g	-	Intelligence
α/β	-	ratio of alpha and beta
α	-	alpha
β	-	beta
δ	-	delta
θ	-	theta
γ	-	gamma
p	-	probability
N	-	number of subjects
df	-	degrees of freedom
F	-	ratio of two variances
t	-	comparison mean of two groups
R^2	-	proportion of the variance
SD	-	standard deviation
SE	-	standard error
η^2	-	eta squared
M	-	mean
λ	-	lambda

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CHAPTER 1

INTRODUCTION

1.1 Background

In recent decades, more cyclists have sought a competitive outlet through competition in sports. Numerous researches have been done exploring the aspects in cycling, such as physiology and psychology (Schücker et al., 2016; Whitehead et al., 2017), biomechanical (Bisi et al., 2012), environment (Schmit et al., 2016), and tactical or strategic (Aisbett et al., 2009).

The advance work through testing, training, research, and education improved cyclists performance as science and technology incorporated an interaction between psychological, physiological, and environmental elements (Faria et al., 2005). Meanwhile, recent developments in mobile EEG technology provide an opportunity to tackle many issues related to neuroscience and sporting behaviour despite facing challenges in moving out from the lab (Park et al., 2015). All of these factors are relevant for any kind of research conducted in the area of cycling competition (Atkinson et al., 2003). Indeed, the environment factor has become a mediator factor in the physiological and psychological changes among cyclists. This complex system is synonymous with endurance sports, such as road cycling (Pageaux, 2014). The external environment that comes from the terrain, wind, and tactical features, as well as the presence of other factors that require pacing adjustment during a race.

In real environment of cycling competition, especially during road cycling event, the element of wind, scenery, competitors (environment), power output, cadence (physiology), pacing strategy (tactical), and brain activity (neuroscience) are vital to determine the cyclists' competitiveness (Konings et al., 2016; Rattray et al., 2017). Recent works by researchers in sports performance found that there are psychological issues involved with the interaction of neuroscience and physiological characteristics. Thus, it is important to understand the central nervous system interactions with peripheral nervous system to generate an efficient motor performance (Enders & Nigg, 2015). Most of the time, this process would occur in implementing a tactical strategy during cycling competition. The individual's cognitive ability is important to process the input and information from external environment and internal neuronal sources to execute the tactical strategy. The cognitive ability and its interactions with physiological functions can be evaluated through neuroimaging technique and electrophysiological measurement.

Some researchers consider the brain activity involvement as a neurophysiological work as it encompasses afferent feedback and central nervous system (Rattray et al., 2017). This mechanism occurs due to the complexity between physiological system and environment that regulates the work rate (power output) (Atkinson et al., 2007). The regulation of brain activity could potentially limit the changes or make some adjustments of work rate due to various factors, such as cognitive ability, experiences (Mauger et al., 2009), and training (Faria et al., 2005). These factors are yet to be understood in the context of general intelligence ability as this cognitive ability contributes towards the ability to solve novel problems or perform logical thinking. Intelligence and exercise have been proven to contribute to the performance in specific sports (Del Percio et al., 2009; Di Fronso et al., 2016). The intelligence described by various terminologies, such as reasoning (Colom et al., 2010), decision making (Di Domenico et al., 2015), creativity (Haier & Jung, 2008), executive function, and neural efficiency (Thatcher et al., 2016) helps in dealing with cognitive function during specific task execution. Currently, cognitive function is typically measured by using functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) as these instruments can assess brain activity during exercise (Fink et al., 2009).

In the context of this study, it is important to note that the brain activity that assesses individual cognition function vary due to the individual's perception, memory, experiences, creativity, intelligence, and knowledge. Thus, as the nature of road cycling competition requires brain regulation to work with physiological capacity to accommodate pacing strategies, especially during attacking, drafting, and feeding, conducting a study to find what lies behind the specific role of road cycling competition is needed. Previous scholars stated that the capacity of cyclist to make the right decision is thoroughly dependent on their intelligence, especially during the pace. The pace requires the individual to adapt with strategies that they have planned before and during the race. This mechanism of brain to change after receiving stimuli from external environment and internal information within the brain occurs in the somatosensory brain area.

Before moving to further details in this research, it is essential to know the scope of intelligence in this study. The scope of study ranges within cognitive performance of intelligence and its interaction with task in road cycling, as well as the physiological functions during the tasks. Due to various definitions and broad terms of intelligence, this study will emulate the terms of the test measured for intelligence. As described by Akdeniz (2018), intelligence refers to the ability to engage in abstract reasoning, known as independent life experiences and knowledge. Thus, stand on intelligence quotient (IQ) test, this study refers to fluid intelligence (*gf*), as a part of general intelligence (Stankov et al., 2006). Deary et al. (2010) explained that the ability to solve problems on-the-spot requires learned method, knowledge, and information. In addition, this definition also refers to inhibition, where individual has the ability to inhibit non-functional information from influencing information processing and to focus the processing on the processing plan and the demands that need to be accomplished (Ren et al., 2017). The intelligence terminologies are broad in nature due to differences of argument from scholars a few decades ago about various situations and perceptions of individual. It also provides a few theories on intelligence that explain different concepts, including individual differences, social interaction, culture, environment, measurement methodologies, and interpretation (Neisser et al., 1996).

While intelligence is discussed in specific context of physical involvement, it is characterised as kinaesthetic intelligence or nonverbal intelligence (Konter, 2010). This term involves the physical ability to move in a dynamic manner, as always relates to sports, such as dance and athletic (Shearer & Karanian, 2017). In the perspective of brain mechanism, intelligence in sports is more likely described as neural efficiency

(Neubauer & Fink, 2009b). In relation to α and β wave ratios, it denotes that higher α and β wave ratios indicate high neural efficiency. This reflects the condition of α waves as explained by cognitive processing. Meanwhile, β waves describe the condition of sensorimotor process (Neubauer & Fink, 2009b). The automatic movement from experts refers to low activation of β waves frequency of spectral power. In contrast, untrained athletes need to move harder, eventually recruiting more neuron interaction, leading to high β waves activation (Ludyga et al., 2016b).

This mechanism involves the cognitive-motor physiological, as the movement execution process is either autonomous or controlled in nature (Wang et al., 2019). In sports, most of the time, psychomotor elements are important in generating and explaining athletic development or deterioration in performance. These elements are related to tasks in specific sports. Previously, the task demands in sport-specific vary and required cognitive ability from creativity, decision making, attention, intelligence, and executive functions. The process of development in cognitive and task demand is separately developed and explained by theorists. In this study, cognitive and task demand are discussed distinctly as well as jointly. This is due to the involvement of different contexts of intelligence and task demands in specific to road cycling event. However, along the way, this study will elaborate these terms in depth, especially towards task demand related to road cycling. Furthermore, this study will also highlight task difficulty as task demand in road cycling.

In research study, task demands are described in accordance to the specified purpose and context of study. Task demands in psychomotor are the ability of motor action to perform specific activity or task, involving the mechanism of central nervous system and peripheral nervous system. Therefore, the psychomotor task related to road cycling reflects the specific task that is commonly performed by cyclists during road competition. The physiological mechanism of brain and physiological functions formulated from previous studies will be linked to the findings in this particular study. Previous studies found that task demands in psychomotor are in the scope of its development, processing, and performance in various sport-specific contexts. It was also discussed with existence of cognitive process as a part of responses in the central and peripheral nervous systems (Wang et al., 2019).

The acts of cognitive-motor actions in road cycling are responses from internal and external cues, such as a cyclist’s individual capabilities, tactical selection, identified road, and unexpected environment. Measuring interaction of task demands with cognitive intelligence might bring issues of real environment versus laboratory experiment. Due to this, virtual reality environment contributes to providing an assessment alternative as well as training tools. The development of virtual reality system required different expertise and fundamentals as this system embeds integration of software, hardware, and human interaction. This tool could potentially be a future platform towards various problematic issues on preparing cyclists for real competition environment and situations.

In response to the interactions between the individual cognitive performance and physiological functions, the task itself will modulate its mechanisms. This study will highlight the physiological functions of neural efficiency, power output, heart rate, and cadence, and how these parameters interact with intelligence in response to task demands in road cycling.

1.2 Thesis Roadmap

The thesis writing will follow the thesis roadmap. This roadmap will provide the directions of study and thesis organization. This thesis will be organized according to the roadmap. It will guide the researcher and readers on how the research was conducted towards the completion. The roadmap is based on the research objective as a guideline of thesis organization. In chapter 2, the focus is on research objective 2. Objective 3 is reviewed in the subsection virtual reality. Objective 4 is mainly to evaluate the procedure of development task difficulty. The result from the evaluation may and may not be compared from previous study as this study is going to develop new tasks specific to road cycling.

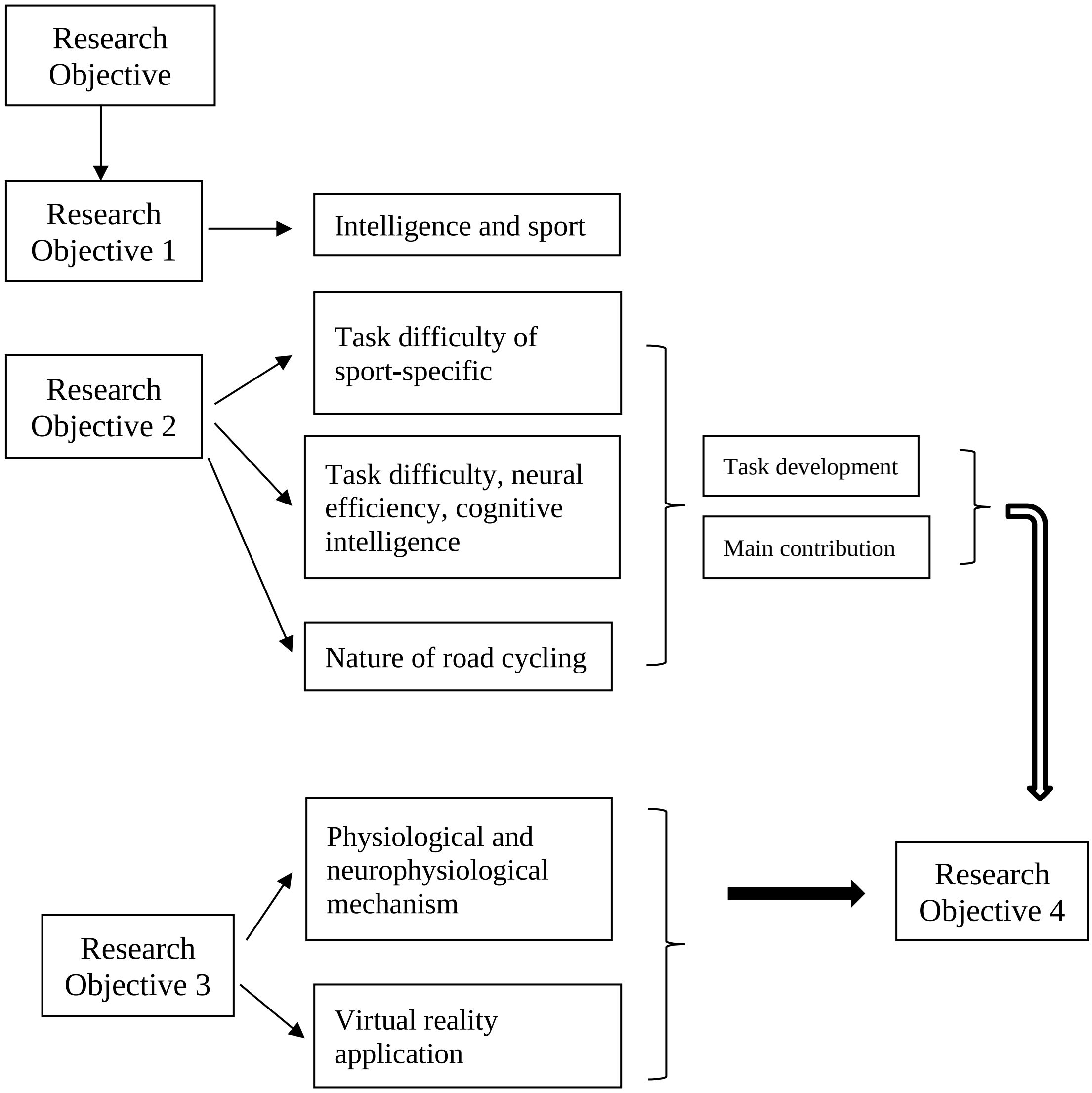

Figure 1.1 Thesis Roadmap of Reseach Objective

1.3 Problem Statement

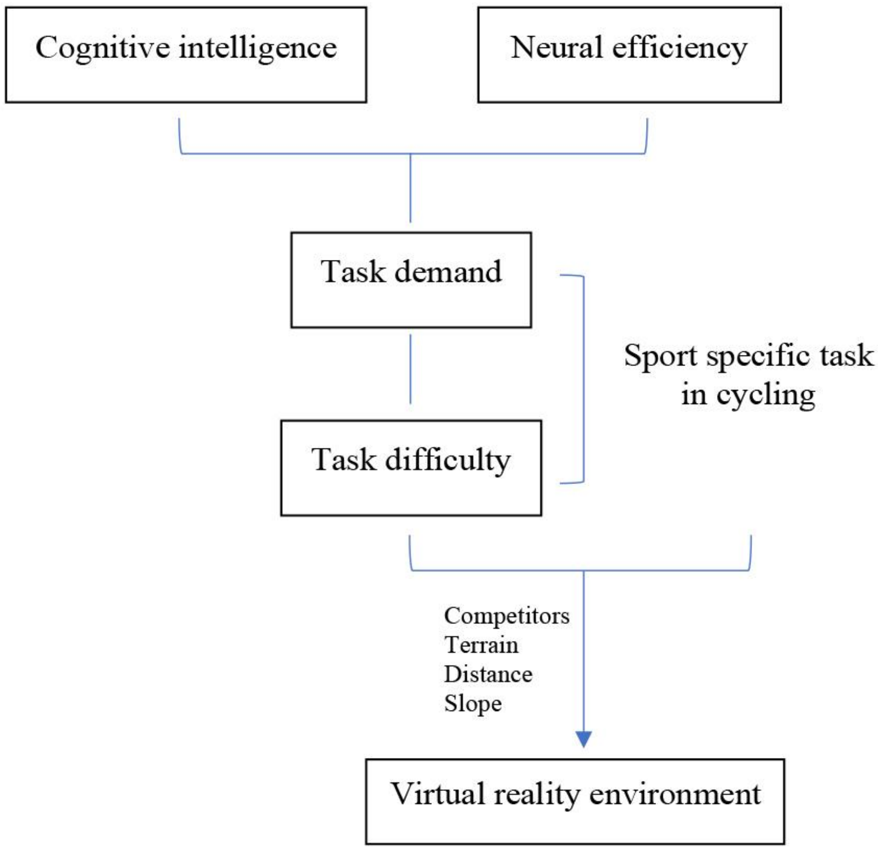

Figure 1.2 Diagram of Problem Statement

Neural efficiency hypothesis previously described in neuroimaging technique showed low activation for high compared to low cognitive performance of individual intelligence (Jung & Haier, 2007). It further explained that brain activation is modulated by task demands (Dunst et al., 2014). For instance, the concept further explored different conditions and several measurements that contributed to these arguments (Qiu et al., 2019). Different conditions and measurements refer to various types of procedures in experimental design as well as different subjects. These circumstances lead to research gap. The findings found inconsistent on the relationship between cognitive performance and neural efficiency as a function of task demands. It may be that such increases reflect cortical activity in a sport-specific context, such as motor imagery (Wei & Luo, 2010), action observation (Calvo-Merino et al., 2005), and sport-related anticipation (Wright et al., 2010).

A few decades ago, the concept of individual intelligence was well-documented by Neisser et al. (1996). Recently, it has been discussed in sport-specific context that dynamic sports serves as environment, and neural mechanism plays an interchangeable role towards neural changes (Chiu et al., 2017). It denoted that cognitive and motor interaction can be explored in its neural mechanism of genetic and environment factors (Leisman et al., 2016). This has to do with the innate structure of neuron and biological to form individual differences traits. However, this study needs instruments to measure neural substrates, such as neuroimaging technique. Furthermore, the exploration on this scope of study expanded towards cognitive abilities (Barnes et al., 2014; Hearne et al., 2016) and psychomotor tasks (Christie et al., 2017). This further leads to exploration in sporting context while psychomotor tasks and sport specific tasks were designed and established to understand the interactions between cognitive intelligence and task demand, as well as its effects on physiological functions.

According to Yarrow et al. (2009), apart from physical fitness, elite athletes must develop sport-specific cognitive abilities that integrate with perception, cognition, and action. Meanwhile, in competitive cycling, especially during high-pressurised situations, brain function plays an important role in regulating physiological functions (Cheron et al., 2016). These interactions involve the cognitive abilities to regulate new information from external factors and integration with working memory. However, research conducted on these issues is still in debate and discussion (Bertollo et al., 2015; Neubauer & Fink, 2009; Yarrow et al., 2009) even though some of them made an effort in the area of neurophysiological (Bullock et al., 2015; Ludyga et al., 2016a, 2016b; Ludyga et al., 2016).

As cyclists are exposed to uncertain environment in long distance ride, the brain activity function remains the issue to regulate information and available physiological capacity, as well as responding with strategies to achieve optimal performance (Atkinson et al., 2007). These cognitive processes involve abstract reasoning as an individual with this ability should be able to solve new specific problems in a logical manner. The capability of an individual to make the right decision in dealing with specific task is closely related to the individual's fluid intelligence

(Neubauer & Fink, 2009b; Yarrow et al., 2009). In the sports context, it is described as an ability of the athletes to respond to opponent's reaction that eventually requires judgement based on available information (Chiu et al., 2017). This situation is a part of road cycling task as cyclist needs to respond to opponents and teammates behaviour (Konings et al., 2017; Mignot, 2016). However, it is not yet understood whether intelligence could influence neural efficiency.

Therefore, the development of instrumentation and procedure to conduct the sport-specific psychomotor tasks induced by specific cognitive elements may provide a better point of view for psychophysiological and cognitive neuroscience in sports. The mental capability towards the function of mechanism neuron activity could explain the required physiological functions and psychomotor movement or tasks (Babiloni et al., 2010; Cheng et al., 2017; Gutmann et al., 2018; Hunt et al., 2013). Study conducted by Neisser et al. (1996) revealed that the connection between intelligence and how individual adapts with different environment is different from sporting environment. However, extensive research has been conducted in multiple sports, especially sports-related contexts to less movement contexts (Costanzo et al., 2016; Duru & Assem, 2018; Guo et al., 2017; Kretchmar, 2018; Laborde et al., 2017; Qiu et al., 2019; Van Biesen et al., 2017). In a study on cycling, the discussion and argument on intelligence from previous studies are related to neural efficiency, while featuring experiment on exhaustion level (Ludyga et al., 2016a, 2016b). In addition, earlier studies employed cycling task to evaluate the effect of acute exercise on cognitive performance (Pontifex & Hillman, 2007). Nevertheless, it showed less evidence on the investigation in cross-sectional study related to sport-specific task in cycling. Apart from various terminologies used to refer to sport-specific task demand, this study intends to focus on the development of task related to road cycling from the level of difficulty.

Currently, as cycling is becoming more competitive, athletes, coaches, trainers and professionals aim to differentiate how races are won and lost. Thus, the emerging field of sports neuroscience seeks to produce better understanding between brain and physiological functions (Park et al., 2015). In cycling, although the task seems predictable, every race has different environment and cyclists need to respond accordingly, especially towards their competitors. In addition, the most common issue in cycling is pacing strategy that can be understood as making a pace between timing and work rate with available energy, in both certain or uncertain environment or situation. The individual's ability in pacing depends on how the brain regulates all information and responds depending on energy sources and physical abilities. These sources and abilities, such as heart rate, power output, and cadence are previously studied as physiological indicators (Borg et al., 2018; Reed, 2013; Reed et al., 2016; Smits et al., 2016). These physiological functions interact with external environment ranging from the distance, competitors, terrain, and slopes. However, to conduct the experiment in these situations is impossible. Therefore, development on specific task is in demand and one of the possible platforms is the virtual reality environment.

This platform can simulate specific environment and can be controlled, which is a more suitable method to conduct a study. Previous studies showed numerous evidence based on the effectiveness of virtual reality system in simulating real environment (Balkó et al., 2018; Cooper et al., 2018; Covaci et al., 2012; Davison et al., 2018; Neumann et al., 2017; Vogt et al., 2015; Zeng et al., 2017). The experiment varies from the rehabilitation process (Matsangidou et al., 2018) towards improving specific skills (Cooper et al., 2018; Zeng et al., 2017), as well as improving sports and human performance (Stinson & Bowman, 2014; Tsai et al., 2019).

In cycling, virtual reality environment is extensively used as an indoor training tool. This system is proven to be effective to monitor the physiological development as it can provide data monitoring. Road cyclists should be able to prepare for their general and specific tasks, such as time-trial, sprinting, and mountain. Study conducted on specific cognitive psychomotor tasks could potentially increase psychological and physiological readiness to attend competitive competition in the virtual reality environment (Zaichkowsky, 2012). Previously, there is one study moving onto establishing virtual reality environment as an exercise tool to improve cognitive performance (Vogt et al., 2015). This indicates possible development in the virtual reality environment towards specific cognitive psychomotor task demand, especially in road cycling.

In summary, Figure 1.1 shows how important issues subsequently contribute to the need of this study. It describes interactions between issues. This study highlights the effect of cognitive intelligence on neural efficiency and physiological functions as modulated by task demand. As the study intended to investigate the interactions during specific cycling task, it designed and developed task demand based on different levels of difficulty in the established virtual reality.

1.4 Research Questions

Research Question 1

(a) What are the individual differences of α and β brain activity during Intelligence Quotient (IQ) test and cycling exercise?

Research Question 2

(b) What are the content developments of task difficulty of road cycling?

Research Question 3

(c) What are the effects of task difficulty on road cycling in the virtual reality on physiological of α/β ratio, heart rate, power output, and cadence?

Research Question 4

(d) What are the interactions of task difficulty and cognitive performance on neural efficiency?

1.5 Research Objectives

1.5.1 To evaluate individual difference of brain activity (α, β waves) during IQ test and cycling exercise.

1.5.2 To develop the content of task difficulty of road cycling in virtual reality.

1.5.3 To analyse the effect of development task difficulty of road cycling in the virtual reality on physiological parameters like heart rate, power output, and cadence.

1.5.4 To analyse the effect and association of task difficulty and cognitive performance on neural efficiency and other physiological functions.

1.6 Significance of Study

This study can help us understand the interactions between cognitive performance and neural efficiency, as well as physiological functions when performing specific task in cycling. The knowledge and application are important, especially during exercise and in competition. The scope of this study touches cognitive neurophysiological perspective, extends the knowledge and provides scientific evidence in this area.

The expectation for major contribution in this study will be the development of sport-specific task in road cycling based on the level of difficulty in the virtual reality. The subsequent contribution of the data analysis is pertaining to the task completion. This contribution provides additional evidence on what happens to the interaction of cognitive and physiological functions, including neural efficiency, when the individual performs the task. In this context of study, it specifically identifies the interactions between brain activity and other physiological functions, while cyclist executes task related to their competition. In addition, since the task difficulty developed ultimately in the virtual reality, it contributes to the body of knowledge regarding the significant virtual reality in assisting users to simulate environment as the tasks and environment are real.

The development of task difficulty will potentially be a guideline to the progress of the task development as well as to the future work towards any sport-specific and psychomotor tasks. This study is important to understand athlete's physiology responses during task execution. As stressed by previous studies, most of studies evaluated cognitive and psychomotor responses separately, thus limiting the findings for interactions between cognitive processing and physiological functions. Previous study highlights the difficulty to evaluate mechanism during the task due to the incapability of instrumentation of brain to synchronise the measurement with other physiological responses. Although this study is out of scope for instrumentation of brain development, it may indirectly give significance contribution towards application in developing specific instrument for neural and physiological assessment.

The idea to develop task difficulty to road cycling of brain activity and its physiological function, is to evaluate the association between their responses by employing the virtual reality. This is not only significant to identify between expert and novice, but also in identifying cyclists who can play specific task entrenched with their cognitive ability. From the results, this study can further explore how cognitive processing responds to physiological demand in specific task.

Measuring both brain activity and physiological functions is significant to determine the synchronisation of these parameters to understand their interactions as far as peak performance is concerned. In addition, this study can also provide alternative tool to investigate brain activity of cyclists in real time. The development of virtual reality induces task difficulty in road cycling following previous studies to denote the effect of virtual reality towards specific tasks (Covaci et al., 2012; Davison et al., 2018; Matsangidou et al., 2018). Virtual reality application is increasingly in demand for sports application. It can also provide platform for sport stakeholders who want to further explore physiological and psychological responses in real time and simulated environment. This tool can potentially predict cyclist and athlete's performance. Therefore, the development of this application will establish multidiscipline fields of interest and expertise in the virtual reality.

Meanwhile, study of cognitive performance in sports could potentially assist coaches to identify the right cyclist for specific function. For example, high intelligence may be assigned to be the main achiever in road cycling and lower intelligence may take responsibility in sprinting, time-trial or short distance event. As for the cyclists, the physiological capacity and their ability to adjust and manipulate external forces, such as air resistance and other real situations, contributes towards major pressure on elite cyclists (Barry et al., 2014).

In summary, the significance of this study focuses on the contribution of knowledge in the field of cognitive neurophysiology, specifically in cycling and generally in sport-specific task. The secondary contribution is towards the promising instruments for the future, especially in conducting experiment in real environment. The last contribution is towards the coaches and cyclists to identify alternatives and new approaches to maximise performance.

1.7 Scope and Limitation of Study

This study is primarily focused on the development of task difficulty in road cycling by employing available virtual reality system. The researchers aim to evaluate interactions of several parameters such as cognitive performance, neural efficiency, power output, heart rate and cadence. The available virtual reality system for the road cycling environment will be a platform for experimental study. The subjects in this study were purposely selected in one small population from the National Sport School. This is important to include important criteria such as hours of training, learning, and training environment, free from brain injuries, other spinal or neural problems. Another important scope of this study is cognitive performance that mainly focuses on fluid intelligence. This study will discuss the elements of fluid intelligence that usually relate to cognitive processing in a sport context. The assessment on neural efficiency employ an electrical neural activity approach and will be compared with neuroimaging technique while reviewing the literature.

Meanwhile, there are several limitations in progressing this study. The first limitation is the virtual reality system that works as a tool in developing task difficulty. This system is able to simulate the presence of visual, auditory and somatosensory input. However, the real environment such as wind is not present in the simulation. It is also not able to integrate with bicycle handling, thus the direction is automatically operated from the system. The second limitation is this study is the cross-sectional design. This type of study design will find limitation on the cause and effect relationship. This is because there is no intervention or treatment implemented towards the subjects.

1.8 Summary

The first chapter of this thesis began with the background of the study and outlined the problem statement that contributes to the formulation of research questions and research objectives. It further found significance of the study that is useful for coaches, athletes, researchers, and practitioners especially related to road cycling. The scope and limitations in this study were also highlighted to ensure the research area to explore and specify the parameters. The operating definition will be presented in the last part of chapter 2 to understand the coverage area and the focus of this study.

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