PHYSICAL FITNESS COMPONENTS AND BONE HEALTH STATUS OF MALAY MALE STATE LEVEL BOXING, MUAY THAI AND SILAT ATHLETES

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By

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KOMPONEN-KOMPONEN KECERGASAN FIZIKAL DAN STATUS KESIHATAN TULANG DALAM KALANGAN ATLIT-ATLIT NEGERI LELAKI MELAYU TINJU, MUAY THAI DAN SILAT

ABSTRAK

Kajian ini telah dijalankan untuk mengkaji perbezaan komponen-komponen kecergasan fizikal dan status kesihatan tulang dalam kalangan atlit-atlit negeri lelaki Melayu tinju, Muay Thai dan silat. Seramai 40 peserta (umur purata: 16.7 ± 1.5 tahun) telah menyertai kajian ini. Mereka telah dibahagikan kepada empat kumpulan, iaitu kumpulan – kumpulan kawalan sedentari, tinju, Muay Thai dan silat dengan 10 peserta bagi setiap kumpulan. Kapasiti paru–paru, anggaran pengambilan oksigen maksima (VO_{2max}), kapasiti–kapasiti anaerobik, kekuatan dan kuasa ekstensi otot isokinetik, kekuatan genggaman tangan, kekuatan belakang dan kaki, kuasa letupan lompat jauh berdiri, ketangkasan 'Illinois', keseimbangan berdiri 'Stork' dan fleksibiliti peserta-peserta telah diukur. 'Bone sonometer' telah digunakan untuk mengukur 'speed of sound' (SOS) tulang 'tibia' dan 'radius' kaki dan lengan dominan dan bukan dominan peserta – peserta. Dapatan utama kajian ini ialah atlit-atlit tinju mempamerkan kekuatan dan kuasa otot isokinetik lengan yang lebih besar dengan signifikan secara statistik ($p<0.05$) berbanding atlit silat, dan juga kuasa otot isokinetik lengan yang lebih tinggi berbanding atlit-atlit Muay Thai. Atlit-atlit tinju juga telah menunjukkan anggaran pengambilan oksigen maksima (VO_{2max}) yang lebih tinggi dengan signifikan secara statistik ($p<0.05$)

berbanding dengan atlit-atlit silat. Perbandingan dengan kawalan sedentari, atlit-atlit tinju, Muay Thai dan silat telah menunjukkan kuasa purata ‘Wingate’ dan kekuatan dan kuasa otot isokinetik kaki dan lengan yang lebih besar dengan signifikan secara statistik ($p<0.05$) berbanding kawalan sedentari. Atlit-atlit tinju dan Muay Thai juga telah menunjukkan anggaran pengambilan oksigen maksima (VO_{2max}) dan kuasa letupan lompatan kaki yang lebih besar dengan signifikan secara statistik ($p<0.01$) berbanding kawalan sedentari. Sebagai tambahan, atlit-atlit tinju juga telah mempamerkan kekuatan genggaman tangan dominan dan bukan dominan yang lebih besar dengan signifikan secara statistik ($p<0.01$) berbanding dengan kawalan sedentari. Selain itu, atlit-atlit Muay Thai telah mempamerkan nilai tulang ‘radius’ bukan dominan (SOS) yang lebih besar dengan signifikan secara statistik ($p<0.05$) berbanding kawalan sedentari. Secara kesimpulannya, kajian ini mendapati atlit-atlit tinju telah mempamerkan kekuatan dan kuasa otot isokinetik lengan yang lebih besar berbanding atlit-atlit silat, dan juga kuasa otot isokinetik lengan yang lebih besar berbanding atlit Muay Thai. Atlit-atlit tinju juga telah menunjukkan kecergasan aerobik yang lebih baik berbanding atlit-atlit silat. Tambahan pula, penglibatan dalam tinju, Muay Thai dan silat mampu meningkatkan komponen-komponen kecergasan fizikal dan status kesihatan tulang seseorang individu berbanding gaya hidup sedentari. Keputusan yang diperolehi daripada kajian ini boleh digunakan sebagai garis panduan untuk memudahkan pembangunan program latihan spesifik untuk atlit-atlit tinju, Muay Thai dan silat, disamping menggalakkan gaya hidup aktif dengan melibatkan diri dalam seni mempertahankan diri seperti tinju, Muay Thai dan silat.

PHYSICAL FITNESS COMPONENTS AND BONE HEALTH STATUS OF MALAY MALE STATE LEVEL BOXING, MUAY THAI AND SILAT ATHLETES

ABSTRACT

This study was carried out to determine the differences in physical fitness components and bone health status among Malay male state level boxing, Muay Thai and silat athletes. A total of 40 participants (mean age: 16.7 ± 1.5 years old) participated in this study. They were divided into four groups, i.e. sedentary control, boxing, Muay Thai and silat groups with 10 participants per group. Participants' lung capacity, estimated maximal oxygen uptake (VO_{2max}), anaerobic capacities, isokinetic muscular strength and power, hand grip strength, back and leg strength, standing long jump explosive power, Illinois agility, standing Stork balance and flexibility were measured. Bone sonometer was used to measure bone speed of sound (SOS) of participants' tibia and radius dominant and non-dominant legs and arms. The main findings in the present study were that boxing athletes exhibited statistically significant ($p<0.05$) greater arm isokinetic muscular strength and power than silat athletes, and higher arm isokinetic muscular power than Muay Thai athletes. Boxing athletes also showed statistically significant ($p<0.05$) higher estimated VO_{2max} compared to silat athletes. Comparison with the sedentary controls, boxing, Muay Thai and silat athletes showed statistically significant ($p<0.05$) greater Wingate mean power, and leg and arm isokinetic strength and power than sedentary

controls. Boxing and Muay Thai athletes also showed statistically significant ($p<0.01$) greater estimated VO_{2max} and jumping leg explosive power compared to sedentary controls. In addition, boxing athletes also exhibited statistically significant ($p<0.01$) greater hand grip strength of dominant and non-dominant hands than sedentary controls. Moreover, Muay Thai group exhibited statistically significant ($p<0.05$) greater radius bone SOS values of non-dominant arm compared to sedentary controls. In conclusion, this study found that boxing athletes exhibited greater arm isokinetic muscular strength and power than silat athletes, and also greater arm isokinetic muscular power than Muay Thai athletes. Boxing athletes also showed better aerobic fitness compared to silat athletes. Furthermore, involvement in boxing, Muay Thai and silat could enhance physical fitness components and bone health status of individuals compared to sedentary lifestyles. The findings obtained from this present study can be used as guidelines to facilitate the development of specific training programmes for boxing, Muay Thai and silat athletes, as well as promoting active lifestyle by engaging in martial arts such as boxing, Muay Thai and silat.

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND OF THE STUDY

Recently, Malaysian athletes from martial art such as boxing, Muay Thai and silat have performed well in international tournaments. During the last South East Asean (SEA) games which was held in August 2017 in Kuala Lumpur, Malaysia, Malaysian athletes especially from martial art's events managed to place themselves on the podium to win the gold medals. The pencak silat's athletes have won 10 gold medals during the SEA games. Meanwhile for Muay Thai and boxing events, Muay Thai athletes successfully won 2 gold medals and boxing athlete won one gold respectively (Kuala Lumpur 2017, 2017).

Nowadays, the popularity of Asian martial arts among youth have been increasing. Several types of martial arts are available in Asian countries, which their disciplines can be distinguished by their specific characteristics (Theeboom and De Knop, 1999). Martial arts which are popular in Asian countries are Pencak Silat (Indonesia), Muay Thai (Thailand), Judo (Japan), Wushu (China), Karate (Japan) and Taekwondo (Korean). Even though boxing is a Western type of martial arts, it has been considered as one of the most popular combat sport in Asian and has been practiced by youth in many countries.

Boxing, Muay Thai and silat are martial arts that involve different types of fighting skills. In boxing, points are awarded to a boxer for landing a clean punch with knuckle area of the glove within target area of the opponent (Davis *et al*., 2013). In Muay Thai, legal techniques in the match include a variety of punches, elbows, knee strikes, kicks and grappling techniques. The Muay Thai athletes try to defeat their opponents by scoring points, knockouts or stoppages using a range of full-contact blows delivered to most parts of the body (Myers *et al*., 2013). In silat matches, the points are awarded for toppling an opponent, successful defensive blocks, and offensive punches and kicks to the chest, abdomen and flanks, leg sweeps and throws. Only strikes with either the arms or legs are legal in the silat matches (Aziz *et al*., 2002). The difference in types of styles, techniques and also rules during competitions could contribute to different physical fitness levels among these athletes.

Physiological profiles of martial art athletes can be influenced by the temporal structure (work to rest ratio and match duration) of their sports, in particular the aerobic and anaerobic fitness requirements that are affected by effort type (e.g. low, medium or high intensity), the duration of such efforts (seconds or minutes), and the duration of pause or rest intervals (seconds or minutes) for athletes participating in their respective combat sport modalities. For instance, the nature of boxing requires athletes to sustain power at a high percentage of maximal oxygen uptake ($VO_{2\ max}$) (Andreato and Branco, 2016; Khanna and Manna, 2006). It was reported that silat athletes have lower aerobic capacity when compared to other martial arts athletes but possess high levels of anaerobic power of the lower body (Aziz *et al.*, 2002). Muay Thai involves predominant anaerobic energy

contribution and it has been suggested that phosphagen system is the dominant energy system due to the speed and explosive nature of this sport (Turner, 2009).

The performance of athletes during competitions can be determined by many factors. The differences in the level of physical fitness components can affect the level or ranking among athletes. According to Guidetti *et al*. (2002), the two basic factors which are related to boxing performance are physical fitness as indicated by individual anaerobic threshold and maximal oxygen consumption, and also upper-body muscular strength as indicated by hand-grip strength. Cappai *et al*. (2012) reported that Muay Thai is a physically demanding activity with great involvement of both the aerobic metabolism and anaerobic glycolysis. Moreover, Shapie *et al*. (2013) mentioned that the nature of silat matches requires athletes to possess both aerobic and anaerobic energy systems. Involvement of both energy systems are important during matches as aerobic metabolism is vital during the low intensity while anaerobic sources contribute a major amount of the total energy required during high intensity bursts.

Bone strength of an individual is determined by bone mineral density which refers to the amount of bone mineral in bone tissue (Njeh *et al*., 2001). Low bone mineral density can increase the risk of bone fractures and lead to osteoporosis. According to Nguyen *et al*. (2004), osteoporotic fracture is caused by reduced bone strength and is related to decreased bone mass and impaired bone architecture. It is well accepted that bone health status of an individual can be enhanced through weight bearing activities which induce

gravitational loading as result of impact with the ground. Running, jumping and martial arts are the types of weight bearing activities which can generate high impact with the ground. It was reported by Leinonen (2013) that even light training exercises of martial arts that include impact such as practising breaking of falls or throws can elicit positive effect on bone health of an individual. Ito *et al*. (2016) suggested that martial arts include high magnitude forces through muscle pulling on the bone, ground reaction force intensified by the absence of footwear to attenuate impact shocks and high impact loading of the skeleton due to repeated falls on the ground. In relation to that, these characteristics would enhance the bone health status of an individual.

Measurements of the physical fitness components and bone health status of athletes are important for providing useful information in selection of athletes, and also designing and developing training programmes to enhance sports performance. In Malaysia, especially in Kelantan state, Boxing, Muay Thai and silat are three types of martial arts which are popular among young population. Muay Thai is a popular martial art in Kelantan state for decades based on demographic reason, in which Kelantan state is located at the border of Thailand, where Muay Thai is originated. To date, information on physical fitness components and bone health status of Malay male Kelantan state level boxing, Muay Thai and silat athletes are limited. Therefore, the present study was proposed.

1.1 PROBLEM STATEMENT

Boxing, Muay Thai and silat are martial arts that involve different types of fighting skills. Besides, durations and number of rounds in the competition are also different between these three martial arts. The difference in types of styles, techniques and rules during competitions of these sports could contribute to different physical fitness levels and bone health status among the athletes. Therefore, the present study was proposed in this study.

1.2 OBJECTIVES OF THE STUDY

General objective:

To compare physical fitness components and bone health status among Malay male sedentary individuals, state level boxing, Muay Thai and silat athletes.

Specific objectives:

1) To determine the differences of physical fitness components among Malay male sedentary individuals, state level boxing, Muay Thai and silat athletes.

2) To determine the differences of bone health status among Malay male sedentary individuals, state level boxing, Muay Thai and silat athletes.

1.3 HYPOTHESES OF THE STUDY

H_{01}: There are no significant differences in physical fitness components among Malay male sedentary individuals, state level boxing, Muay Thai and silat athletes.

H_{A1}: There are significant differences in physical fitness components among Malay male sedentary individuals, state level boxing, Muay Thai and silat athletes.

H_{02}: There are no significant differences in bone health status among Malay male sedentary individuals, state level boxing, Muay Thai and silat athletes.

H_{A2}: There are significant differences in bone health status among Malay male sedentary individuals, state level boxing, Muay Thai and silat athletes.

1.4 SIGNIFICANCE OF THE STUDY

To our knowledge, to date, information of physical fitness components and bone health status of Malay male state level athletes of boxing, Muay Thai and silat in Malaysia

are limited. Therefore the present study was proposed. The results of the present study will add new scientific information on the physical fitness components and bone health status of boxing, Muay Thai and silat athletes in the field of sports science in Malaysia. The results obtained from this study can be applied in selection of potential boxing, Muay Thai and silat athletes and help to facilitate the development of specific training programmes for optimal performance of practitioners of these three martial arts. It is hoped that sport organisations, coaches and athletes can apply the results obtained from this study for maximising an individual potential in the field of boxing, Muay Thai and silat.

1.5 OPERATIONAL DEFINITIONS

1.5.1 Physical fitness components:

The components of physical fitness that were measured in this study were lung function, aerobic capacity (estimated VO_{2max}), Wingate anaerobic capacity, muscular strength and power (i.e. isokinetic muscular peak torque and power, hand grip strength, back and leg strength and standing long jump explosive power), agility, balance and flexibility.

1.5.2 Bone health status:

Measurement of bone health status via quantitative ultrasound measurement of bone speed of sound (SOS, $m.s^{-1}$) which reflects bone mineral density.

1.5.3 Malay male state level boxing, Muay Thai and silat athletes:

A group of Malay male state level athletes from three different types of sports, i.e. boxing, Muay Thai and silat who represented Kelantan state of Malaysia with age ranging between 15 to 20 years old.

CHAPTER 2

LITERATURE REVIEW

2.1 PHYSICAL FITNESS COMPONENTS

The American College of Sports Medicine (ACSM) has defined that “physical fitness is the ability to perform moderate to vigorous levels of physical activity without undue fatigue and capability of maintaining such ability throughout life” (American College of Sports Medicine, 2014). Physical fitness can be divided into two components, which are health related fitness and skill related fitness. Health related fitness consist of cardiorespiratory endurance, body composition, musculoskeletal fitness, flexibility, muscular strength and endurance, whereas skill related fitness are agility, balance, coordination, speed, power and reaction time (Nieman, 2011).

Cardiorespiratory endurance refers to the ability of an individual to perform large muscle, dynamic, moderate to vigorous intensity exercise for prolonged periods of time (American College of Sports Medicine, 2014). Cardiorespiratory endurance can be measured through maximal oxygen uptake (VO_{2max}). It is well-accepted that individuals with high VO_{2max} values have been regarded traditionally as possessing "endurance fitness' or "cardiorespiratory fitness" (Ramsbottom *et al*., 1988). Direct measurement of maximum oxygen uptake (VO_{2max}) is recognised as the best single index of aerobic

fitness. Then, the most valid physiological indicator of a subject's cardiovascular function is a laboratory determination of maximal oxygen uptake (VO_{2max}) (Cooper *et al*., 2005). Nevertheless, the direct measurement of VO_{2max} demands sophisticated instrumentation, laboratory time, and trained personnel, and it may not be appropriate for certain situations. For instance, these measurements are not practicable for testing large groups of individuals. Therefore, indirectly measurement or predictive tests like 20-m shuttle run test has been developed that can serve as convenient alternatives to direct VO_{2max} measurements (Stickland *et al*., 2003). Based on the result of previous studies, 20-m shuttle run test has been considered as reliable and valid methods to evaluate aerobic fitness and predict the VO_{2max} of individuals (Leger and Lambert, 1982; Ramsbottom *et al*., 1988; Stickland *et al*., 2003; Chatterjee *et al*., 2010). The 20-m shuttle run test is a well-designed evaluation of maximal work capacity that allows prediction of VO_{2max} from several regression equations. Leger and Lambert (1982) reported that the correlation between the maximal oxygen uptake measurement in the laboratory and 20-m shuttle run test was high ($r = 0.975$), and suggesting that 20-m shuttle run test is a reliable test for predicting VO_{2max} of individuals. The relationship between 20-m shuttle run test performance and VO_{2max} is different between males and females, and consequently the use of gender-distinct equations is strongly advised (Stickland *et al*., 2003).

Furthermore, it was found that maximal oxygen uptake (VO_{2max}) and pulmonary function may have a close correlation. Based on the previous study by Fatemi *et al*. (2012), it was found that dynamic variables of pulmonary function are associated with VO_{2max} levels, and the results also suggested that pulmonary limitation can limit the aerobic

capacity and athletic performance. Moreover, Vedala *et al*. (2013) also found that the pulmonary function in athletes was higher compared to normal sedentary control individuals. They also suggested that regular exercise has an important role in determining and improving lung functions. In addition, different type of sports also contributes to different level of pulmonary functions. According to Durmic *et al*. (2015), the type of sports played has a significant impact on the physiological adaptation of the respiratory system. Based on the result of previous study, the values for spirometric parameters were highest among the athletes who engaged in water polo, which is a representative of water-based sport, than among those who engaged in other sports involving the same type and intensity of exercise. One of the reasons of greater pulmonary function among athletes in water-based sports is because of swimming on a regular basis alters the elasticity of the lungs and of the chest wall, which leads to further improvement in the lung function of swimmers and of athletes who engage in other water-based sports (Durmic *et al*., 2015).

Anaerobic capacity is defined as the maximal amount of adenosine triphosphate resynthesised via anaerobic metabolism (by the whole organism) during a specific mode of short-duration maximal exercise (Green and Dawson, 1993). The ability to develop maximal anaerobic capacity is critical for success in many sports. A number of sports require explosive bursts of activity lasting from a few seconds to 1 to 2 minutes. Activities of this intensity and duration rely heavily on anaerobic metabolic pathways, namely the ATP-PC pathway and the glycolytic pathway (Coppin *et al*., 2012). Therefore, Wingate anaerobic test (WAnT) has been established to measure anaerobic capacity as it measures the muscles' ability to work using both the ATP-PC and glycolytic systems (Zupan *et al*.,

2009). The WAnT measures lower-body peak power, anaerobic capacity and the reduction of power, known as fatigue index. It is a 30-second supramaximal exercise test where an individual pedals as fast as possible on a cycle ergometer against a resistance determined as a percentage of body mass. In addition, the test is considered safe, easy to administer, reliable, and valid and uses equipment common in most laboratories (Coppin *et al*., 2012). A previous study by Gacesa *et al*. (2009) found that athletes from different types of sports have different levels of anaerobic capacity. Furthermore, the researchers found that anaerobic power and capacity show high values in anaerobic types of sports such as volleyball, basketball, hockey, boxing, and wrestling, whereas smaller amounts of anaerobic energy production are observed in sports like soccer, rowing, and long distance running, which are predominantly aerobic types of sports.

Strength is the ability to produce or generate force whereas power is the ability to produce or generate force quickly, which is a function of time and/or speed of movement (Binkley, 2016). Therefore, muscular strength refers to the muscle's ability to exert force and muscular power is the muscle's ability to exert force per unit of time (American College of Sports Medicine, 2014). Related to sports performance, muscular power and strength are known to be influenced by many factors. The two factors that athletes and coaches can control are exercise and nutrition habits (Ozgur, 2012). Due to these two factors, it was believed that different types of sports would have different types of strength and power as different sports will have different requirements for strength and power. Regarding the measurements of strength and power, there are several tests that can be done to measure muscular strength and power in athletes. For instance, strength testing

that can be done with isokinetic strength, hand grip strength or back and leg strength tests, while for power, tests such as isokinetic average power, standing long jump and vertical jump tests can be used.

Isokinetic strength testing had gained a great deal of popularity among the researchers nowadays because it provides an objective means of quantifying existing levels of muscular strength. It provides objective measures of concentric dynamic strength. In addition, it also provides optimal and efficient loading of muscles and joints through range, thereby minimising potential risk for injury (Takey *et al*., 2010). The isokinetic strength testing can be performed to test concentric or eccentric muscle strength at fixed angular velocities. The recorded strength is a measure of the net effect of the force developed by the testing muscles to move the testing joints into extension and flexion. The net effect of these forces exerted around the joints can be recorded over a substantial range of motion (often 90°) at fixed speeds (often 60°/s and/or 300°/s). At low speeds (i.e., 0–180°/s), peak force reflects pure muscle strength, while neuromuscular control comes into play at higher speeds (>180°/s). Testing at higher speeds better reflects muscle function during athletic activities than testing at lower speeds. In addition to peak torque values, ratios of peak torque are often calculated. These ratios provide important information about the relative strength of different muscle groups, or muscle imbalances, and thereby facilitate comparisons between subjects without the need for normalisation (Willigenburg *et al*., 2014).

Nevertheless, the application of isokinetic testing requires expensive devices and assistance from the experts to conduct the tests. Hence, other options that can be employed to measure muscular strength are using hand grip and back and leg strength tests. The application of these methods can be considered reliable and valid as the results from the studies can be compared to standard population normative data. According to Roberts *et al*. (2011), hand grip strength was the only assessment technique recommended for the measurement of muscle strength, and was the simplest method for assessment of muscle function in clinical practice. It can be measured quantitatively using a hand grip dynamometer. The Jamar hand dynamometer appears to be generally accepted as the gold standard by which other dynamometers are evaluated, and has the most normative data (Roberts *et al*., 2011).

Regarding the appropriate measurement for explosive power of the lower body, standing long jump is one of the field tests that can be used to measure explosive power of athletes. It is an index representing leg or kick explosive power. Lockie *et al.* (2016) reported that there is close relationship between leg powers and jumping ability of an individual, hence, maximal jumping test like standing long jump test has been considered reliable to measure explosive power of lower body. In addition, Al-Muzaini and Fleck (2008) mentioned that the advantages of standing long jump test are the test is easy to administer and generally non-fatiguing, and this test also show stronger correlations with some types of power-oriented activities.

Flexibility, it is the ability to move a joint through its complete range of motion (American College of Sports Medicine, 2014). Flexibility is an important component of physical fitness, and is considered a significant contributing factor for optimal athletic performance. Moreover, athletes must have sufficient musculoskeletal flexibility to meet the demands of their sports, otherwise, top performance may not be achieved and injury risk may increase (Golant, 2016). Flexibility measures can be static, dynamic-passive or dynamic-active (Gleim and McHugh, 1997). Sit and reach test is one of the useful alternative to measure flexibility. This test has the advantage of allowing for an evaluation in a short amount of time with minimal skills and instruments (Mayorga-Vega *et al*., 2014). According to Sheppard and Young (2006), agility has been defined as a rapid whole body movement with change of velocity or direction in response to a stimulus. In addition, Lefterov and Zlatev (2016) mentioned that agility is the basis of mastering the complex technical and tactical actions in terms of coordination and synchronization. It is an essential component in most field requiring high speed action (acceleration, maximal speed) and specially team sports competition (Homoud, 2015). Regarding the measurement of agility, the testing is generally confined to tests of physical component such as change of direction speed, and cognitive components such as anticipation and pattern recognition. Therefore, in the present study, Illinois agility test was used to measure agility of the participants.

Balance is one of the skill related physical fitness components which is important to the maintenance of equilibrium while stationary or moving. According to Bressel *et al*. (2007), balance can be defined as the ability to maintain a base of support with minimal

movement and dynamically as the ability to perform a task while maintaining a stable position. The factors affecting balance are breathing, vision, vestibular function, and musculoskeletal alignment and proprioception. According to Panta *et al*. (2015), one of the tests that is recommended to evaluate static balance and can be of value in research purposes is Stork stand test. The Stork stand test is used to monitor the development of the individual's ability to maintain a state of equilibrium (balance) in a static position. In addition, the advantages of the test is that no equipment required, it is simple to set up and conduct, and it can be conducted almost anywhere.

2.2 INTRODUCTION AND TYPES OF MARTIAL ARTS

Martial arts have been practiced for thousands of years. They are often defined as offensive and defensive combat systems with or without weapons. Nowadays, modern martial arts usually have their origins in the Orient, and are typically combat arts that have been modified for sports, self-defense and recreation (Woodword, 2009). There are about 200 distinct disciplines of martial arts, which has its own traditions of training and philosophy. Each discipline has different facets that make them unique (Bu *et al*., 2010). According to Biernat *et al*. (2013), martial arts and combat sports belong to a group of hand to hand combat sports styles with some of them are based on punching (e.g. boxing and its variations – Burmese, French or Thai boxing, karate, kick-boxing, sanshou, taekwondo), while other techniques are based on grappling (e.g. Brazilian jiu-jitsu, judo,

sambo, sumo, wrestling and its variations, lutalivre, ssirum, submission fighting, catch wrestling), grappling and punching (e.g. jiu-jitsu, mixed martial arts, pankration, shoot boxing) or combat with weapons (e.g. kendo, fencing).

Today, Asian martial arts are popular among youth all over the world. In general, Asian martial arts practice consists of three forms which are individual routines, partner routines and free fights (Theeboom and De knop, 1999). In addition, all martial arts disciplines can be distinguished by their specific characteristics. Some of the most popular examples of martial arts in Asian countries are Wushu (China), Judo (Japan), Karate (Japan), Taekwondo (Korean), Pencak Silat (Indonesia) and Muay Thai (Thailand). Furthermore, Van Dijk *et al*. (2014) mentioned that martial arts are often considered as either soft, such as Tai Chi and Yoga, or hard, such as Tae Kwon Do, Kung Fu, and Karate. Generally, hard martial arts focus on powerful execution of a limited number of movement techniques (those which most quickly and successfully take the opponent out), whereas soft martial arts primarily value the quality of execution of a much wider variety of movements, without losing sight of the fact that these movements relate to defense and attack patterns.

2.2.1 Martial arts sports and physical fitness components

"Martial arts" is a general term for many forms and styles of martial art, which includes boxing, Muay Thai and silat (Douris *et al*., 2004). All martial arts disciplines can

be distinguished by their specific characteristics. Due to the many movements and skills involved during martial arts practices or competitions, it is believed that martial arts athletes will have better physical fitness components and bone health status when compared to the sedentary individuals. Furthermore, the differences between martial arts sports also can be distinguished between them as suggested by Andreato and Branco (2016) that the physiological profile of combat sport athletes is influenced by the temporal structure (work to rest ratio and match duration) of their sport, in particular the aerobic and anaerobic fitness requirements that are influenced by effort type (e.g. low, medium or high intensity), the duration of such efforts (seconds or minutes), and the duration of pause/rest intervals (seconds or minutes) for athletes participating in their respective combat sport modalities.

Regarding the previous studies of martial arts on physical fitness, Douris *et al*. (2004) reported that individuals who practiced soo bahk do (a Korean martial art similar to karate) exhibited greater aerobic capacity, balance, flexibility, muscle endurance and strength, and less body fat than the sedentary controls who were matched for age and sex. They also reported that martial arts can be considered as an excellent form of exercise for promotion of fitness in adults. Alm and Yu (2013) also found that one year practice in mixed martial arts would improve aerobic and anaerobic capacity. Furthermore, a previous study on elite Brazilian Jiu-Jitsu athletes also found that these athletes have good aerobic power, medium flexibility, excellent maximal isometric back strength, excellent abdominal and upper body strength endurance (Andreato *et al*., 2011). In addition, Van

Dijk *et al.* (2014) also mentioned that hard martial arts practice can improve physical fitness functions in healthy people over 40 years old.

Moreover, due to differences in their training methods and match requirements, some previous studies also reported that there were differences in physical fitness components between these martial arts sports. It was found that Muay Thai athletes have greater agility compared to Brazilian Jiu Jitsu and Judo athletes. Similarly, Brazilian Jiu Jitsu and Judo athletes have greater strength compared to Muay Thai athletes. The result of previous study suggested that those training for Muay Thai rely more on quickness and speed while those training for Jiu Jitsu or Judo rely more on strength (Jungman and Wilson, 2016). Another study by Busko (2016) which investigated the muscular strength of judoist, boxers and taekwondo athletes found that these three martial arts had produced different type of muscular strengths. It was believed that the differences in their strengths were due to the characteristics of the discipline and the training methods used. In addition, in martial arts, the training undergone by the athletes and their participation in competitions can be expected to affect their strength. Different levels of physical fitness components were also reported in the previous study by Schwartz *et al*. (2015) which compared between groups of martial arts such as Brazilian Jiu Jitsu, judo, karate, kung-fu and taekwondo.

2.3 INTRODUCTION TO BOXING

Boxing is one of the most popular games, especially in Europe and the Americas (History of boxing, 2018). Legends like Muhammad Ali, Mike Tyson along with many stars have brought worldwide fame and recognition to the sport. Historically, boxing can be traced back over 5,000 years to ancient Egypt. In addition, earliest evidence suggests that boxing was prevalent in North Africa about 4000 BC and the Mediterranean in 1500 BC (Delvecchio, 2011). Prior to 1866, Jack Broughton was credited with establishing a set of rules for boxing (History of boxing, 2018). As a consequences, boxing has become a competitive sports until now. Furthermore, boxing made its Olympic debut at the Games of the III Olympiad in St Louis in 1904. Since its inclusion in the Olympic programme, boxing has been staged at each edition of the Games, except in 1912 in Stockholm, owing to Swedish law, which forbade the practice (International Olympic Committee, 2017).

Boxing is a combat sport in which athletes try to strike and/or defend themselves from the attacks of their opponents (De Lira *et al*., 2013). This sport is supervised by a referee over a series of one- to three-minute intervals called rounds. Then, the result is decided when an opponent is deemed incapable to continue by a referee, is disqualified for breaking a rule, resigns by throwing in a towel, or is pronounced the winner or loser based on the judges' scorecards at the end of the match (Singh and Singh, 2016). The aim of this combat sport is to punch one's opponent without being punched in return (Davis *et al*., 2013). As consequences, a boxer requires for landing a clean punch with the knuckle

area of the glove to any part of the front or sides of the head or body above the belt to gain the points, before become the winner either by scoring points, knockdown or knockout. Meanwhile, defensive movements are also made by boxers with the feet, torso, and hands to evade punches from their opponents (Davis *et al*., 2013).

2.3.1 Boxing and physical fitness components

Boxing matches are characterised by dynamic phases of short duration, which involve almost all muscle groups in complex movements characterised by short phases of maximal and/or supramaximal effort intensity, which lead to rapid accelerations and decelerations of body segments (De Lira *et al*., 2013). El-Ashker and Nasr (2012) also mentioned that the matches is characterised by high intensity movements during limited rounds, with short breaks which are insufficient for full recovery. Therefore, boxing requires significant anaerobic fitness, and operates within a well-developed aerobic system. It is estimated to be 70-80% anaerobic and 20-30% aerobic (Ghosh *et al*., 1995). In addition, Delvecchio (2011) had mentioned that boxing is a sport that requires a high aerobic capacity (VO_{2max}), a well-developed anaerobic system (Lactate Tolerance) and possibly good grip strength.

According to El-Ashker and Nasr (2012), regular boxing exercise induces physiological changes by lowering resting heart rate, increase aerobic and anaerobic performance. The differences between levels of boxing training also affect the physical

fitness components between boxers. In a previous study by Khanna and Manna (2006) which compared the physiological profiles of senior and junior boxers had reported that senior boxers have higher aerobic and anaerobic fitness compared to junior boxers. Moreover, significantly higher strength of back and grip were also noted in senior players compared to juniors. It was believed that a very high intensive and long duration interval training are needed to develop the needs to be incorporated in the training schedule to develop both the aerobic and anaerobic components of the boxers to meet the demand of the game (Khanna and Manna, 2006).

Guidetti *et al*. (2002) had reported that two basic factors that can determine the performance of each boxer were high aerobic and anaerobic levels, and greater hand grip strength. Hence, high level of aerobic and anaerobic energy systems would allow the boxer to perform at a higher intensity level during subsequent rounds avoiding exercise impairment and reducing muscle tension development due to blood lactate accumulation. Furthermore, Davis *et al*. (2015) also suggested that elite level boxers should not only be sufficiently physically conditioned to avoid early fatigue but they need to be able to increase their activity rate and punching accuracy with subsequent rounds. In addition, development of muscular strength is also important for boxing athletes as optimum punching force is fundamental to successful boxing performance (Cheraghi *et al*., 2014).

According to Guidetti *et al*. (2002), the greater hand grip strength among boxers was dependent on the strength of arm muscles and also of shoulder muscles. During

boxing movements, different muscles are activated to a different extent depending on the types of punches that were used. Besides, lower body motion also play an important role to develop optimum punching force among boxers. According to Cheraghi *et al*. (2014), leg drive has been observed to build-up momentum in the kinematic chain helping towards greater fist velocity and the effective mass. Therefore, specificity of strength training should focus on both upper and lower body kinematics of each boxer.

2.4 INTRODUCTION TO MUAY THAI

Muay Thai, often translated into English as Thai boxing, is the national sports of Thailand and is a martial arts with origins in the ancient battlefield tactics of the Siamese army (Crisafulli *et al*., 2009). According to Saengsawang *et al*. (2015), Muay Thai has been considered as a weapon for the Thai people to protect the land from other nations in every period such as Sukhothai, Ayutthaya, Thonburi and Rattanakosin and is developed to the present. There are several types of Muay Thai which are different in techniques and styles, but they came from the same root such as Muay Korat, Muay Chai Ya, Muay Uttaradit, Muay Lopburi, Muay Phranakhon, Muay Sakhon Nakhon, etc. In addition, Muay Thai comprises of 65 techniques which are 15 punch techniques, 15 foot techniques, 11 knee techniques, and 24 elbow techniques. Additionally, there are 82 Muay Thai tactics consisting of 29 boxing punches against tactics, 3-knee against tactics, 4-elbow against

tactics, and 23 attack tactics. There are also 15 major techniques and 15 minor techniques of Muay Thai (Saengsawang *et al*., 2015).

During the late 20th century, Muay Thai gained popularity. Then, under a unified governing body, the sports spread to 110 countries with five continental federations. In addition, Muay Thai has multiple applications in other sports such as American and European kickboxing, karate (multiple forms), and mixed martial arts (Trial and Wu, 2014). Muay Thai event requires athletes to compete in an international style boxing ring, where they try to defeat their opponents by scoring points, knockouts or stoppages using a range of full-contact blows delivered to most parts of the body. Legal techniques in the sports include a variety of punches, elbows, knee strikes, kicks and grappling techniques (Myers *et al*., 2013). Muay Thai matches last up to 5 rounds of 3 minutes, but it is often manipulated depending on the skills of the athletes (Turner, 2009). Similar to boxing, the outcome of a match is decided either by knockouts, technical knockouts, or points, based upon a system adapted from the Queensbury Rules (Trial and Wu, 2014).

2.4.1 Muay Thai and physical fitness components

Muay Thai is known as a physically demanding activity with great involvement of both the aerobic metabolism and anaerobic glycolysis (Crisafulli *et al*., 2009; Cappai *et al*., 2012). Thus, it was suggested that the training protocols for Muay Thai should include exercises that train both aerobic and anaerobic energetic pathways (Crisafulli *et*